Swiss Needle Cast Cooperative

Annual Report 2006

Oregon State University

Swiss Needle Cast Cooperative

Edited by David Shaw

Layout by Gretchen Bracher, FCG

Income Sources and Expenditures, 2006

Income	
Membership dues	107,500
Oregon State Legislature	95,000
Carry-over	21,263
Total 2006 Budget	**223,763**
Expenditures	
Salaries and Wages	81,588
Supplies and Services	99,719
Travel	1,500
Indirect Costs	23,765
Total Expenditures	**206,572**
Net total	**17,191**

CONTENTS

To: SNCC Members
From: David Shaw, SNCC Director
Date: October, 2006
Subject: 2006 Annual Report

The Swiss Needle Cast Cooperative formally began in January 1997, and our first Annual Report came out in 1998. This 2006 Annual Report is our ninth. From those early days when we didn't quite know what was going on, until today, when our understanding of the epidemic is much more sophisticated, we have led the way in research and management of the disease. The Cooperative is currently focusing on 4 core areas where funding seems especially important to advance the interests of landowners and tree growers in the region of the SNC epidemic. These include epidemiology, silviculture, soils, and tree improvement. This Annual Report includes 11 contributions from researchers working on these various aspects of SNC impacts and control.

The SNC Cooperative is committed to continuing epidemiology studies, with the annual aerial survey a priority because it allows us to determine the seriousness of the disease, but it is also enabling us to understand the relationship of visible symptom expression and weather patterns. We continue to support work on a model that will predict the spatial geographic variation in SNC severity, while in 2006, we collaborated with USFS and ODF to remeasure the Cascade plots established by Floyd Freeman five years ago.

The SNCC has long supported silviculture and mensuration research and in 2006 the large plot network that is currently in place is being utilized to support development of an ORGANON subroutine that allow predictive modeling of volume production based on stand level foliage retention estimates.

In 2006 we supported the effort by Doug Maguire and colleagues to begin a major regional tree nutrition project that will test for the effects of key nutrients in forest growth and productivity, and determine if soil amendments affect susceptibility to SNC. We have also supported a preliminary investigation into the health of soil microbial communities in SNC affected stands.

Finally, we have begun collaborations with the Northwest Tree Improvement Cooperative and it's cooperating cooperatives who have already initiated tree improvement projects in the zone of the SNC epidemic. There is a strong willingness among these groups to work with the SNCC to determine mechanisms and other factors associated with SNC tolerance in Douglas-fir.

Our current budget picture is good for the next year, as membership dues and Oregon state legislature monies will enable us to fund approximately $200,000 in research projects for 2007.

Sincerely,

David Shaw

Projects for 2006

- Continue aerial survey to monitor SNC in Oregon Coast Range.
- Continue Growth Impact Study and Precommercial Thinning Study.
- Remeasure plots that had sulfur treatments.
- Remeasure Cascade Mts. Plots established 5 years ago to determine if SNC is a problem in the Cascades.
- Develop submodule for ORGANON to predict growth of Douglas-fir under different severities of SNC.
- Establish fertilizer study to determine if soil amendments affect susceptibility to SNC.
- Continue to develop a model that will predict the spatial geographic variation in SNC severity.
- Begin a preliminary investigation into the health of soil microbial communities in SNC affected stands.

Background and Organization

A major and recent challenge to intensive management of Douglas-fir in Oregon and Washington has been the current Swiss Needle Cast (SNC) epidemic. Efforts to understand the epidemiology, symptoms, and growth losses from SNC have highlighted gaps in our knowledge of basic Douglas-fir physiology, growth, and silviculture. The original mission of the Swiss Needle Cast Cooperative (SNCC), formed in 1997, was broadened in 2004 to include research aiming to ensure that Douglas-fir remains a productive component of the Coast Range forests.

SNCC is located in the Department of Forest Science within the College of Forestry at Oregon State University. The Membership is comprised of private, state, and federal organizations. Membership dues vary depending on forestland ownership. One annual report, project reports, and newsletters are distributed to members each year. All projects are carried out in cooperation with specific members on their land holdings.

Mission Statement

To conduct research on enhancing Douglas-fir productivity and forest health in the presence of Swiss needle cast and other diseases in coastal forests of Oregon and Washington.

Objectives

(1) Understand the epidemiology of Swiss needle cast and the basic biology of the causal fungus, Phaeocryptopus gaeumannii.

(2) Design silvicultural treatments and regimes to maximize Douglas-fir productivity and ameliorate disease problems in the Coast Range of Oregon and Washington.

(3) Understand the growth, structure, and morphology of Douglas-fir trees and stands as a foundation for enhancing productivity and detecting and combating various diseases of Douglas-fir in the Coast Range of Oregon and Washington.

List of Refereed Publications

2000

Hansen, E.M., Stone, J.K., Capitano, B.R., Rosso, P., Sutton W., Winton L., Kanaskie A., and M.G. McWilliams. 2000. Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in coastal Oregon. Plant Disease. 84: 773–779.

Manter, D.K., Bond, B.J., Kavanagh, K.L., Rosso, P.H., and G.M. Filip. 2000. Pseudothecia of Swiss needle cast fungus, Phaeocryptopus gaeumannii, physically block stomata of Douglas-fir, reducing CO_2 assimilation. New Phytologist 148: 481–491.

2001

Kastner, W., Dutton, S., and D. Roche. 2001. Effects of Swiss needle cast on three Douglas-fir seed sources on a low-elevation site in the northern Oregon Coast Range: Results after five growing seasons. West. Jour. of Ap. For. 16(1):31-34.

Manter, D. K., Kelsey, R. G., and J. K. Stone. 2001. Quantification of Phaeocryptopus gaeumannii colonization in Douglas-fir needles by ergosterol analysis. For. Path. 31: 229–240.

2002

Maguire D.A., Kanaskie A., Voelker W., Johnson R., and G. Johnson. 2002. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. West. Jour. of Ap. For. 17: 86–95.

Johnson, G.R. 2002. Genetic variation in tolerance of Douglas-fir to Swiss needle cast as assessed by symptom expression. Silv. Gen. 51: 80-86.

Maguire, D.A. and A. Kanaskie. 2002. The ratio of live crown length to sapwood area as a measure of crown sparseness. For. Sci. 48: 93-100.

Manter, D. K. 2002. Energy dissipation and photoinhibition in Douglas-fir needles with a fungal-mediated reduction in photosynthetic rates. J. Phytopathol. 150: 674–679.

Winton, L. M., Stone, J. K., Watrud, L. S., and E. M. Hansen. 2002. Simultaneous one-tube quantification of host and pathogen DNA with real-time polymerase chain reaction. Phytopathology. 92: 112–116.

2003

Johnson, G.R., Gartner, B.L., Maguire, D., and A. Kanaskie. 2003. Influence of Bravo fungicide applications on wood density and moisture content of Swiss needle cast affected Douglas-fir trees. For. Ecol. Man. 186: 339-348.

Manter, D.K., Bond, B.J., Kavanagh, K.L., Stone, J.K., and G.M. Filip. 2003. Modelling the impacts of the foliar pathogen, Phaeocryptopus gaeumannii, on Douglas-fir physiology: net canopy carbon assimilation, needle abscission and growth. Ecological Modeling. 164: 211–226.

Manter, D.K., and K.L. Kavanagh. 2003. Stomatal regulation in Douglas-fir following a fungal-mediated chronic reduction in leaf area. Trees : structure and function. 17:485-491.

Manter, D.K., Winton, L.M., Filip, G.M., and J. K. Stone. 2003. Assessment of Swiss Needle Cast Disease: Temporal and Spatial Investigations of Fungal Colonization and Symptom Severity. Phytopath-Z. 151:344-351.

Rosso, P. and E.M. Hansen. 2003. Predicting Swiss Needle Cast disease distribution and severity in young Douglas-fir plantations in coastal Oregon. Phytopathology 93: 790-798.

Winton, L.M., Manter, D.K., Stone, J.K., and E.M. Hansen. 2003. Comparison of biochemical, molecular and visual methods to quantify Phaeocryptopus gaeumannii. Douglas-fir foliage. Phytopathology. 93: 121–126.

2004

El-Hajj,-Z., Kavanagh,-K., Rose,-C., and Z. Kanaan-Atallah. 2004. Nitrogen and carbon dynamics of a foliar biotrophic fungal parasite in fertilized Douglas-fir. New Phytologist. 163: 139-147.

Grotta, A.T., Leichti, R.J., Gartner, B.L., and G.R. Johnson. 2004. Effect of growth ring orientation and placement of earlywood and latewood on MOE and MOR of very-small clear Douglas-fir beams. Wood and Fiber Science. 37: 207-212.

Kelsey, R.G., and D.K. Manter. 2004. Effect of Swiss needle cast on Douglas-fir stem ethanol and monoterpene concentrations, oleoresin flow, and host selection by the Douglas-fir beetle. For. Ecol. Man. 190: 241-253.

Temel, F., Johnson, G.R., and J.K. Stone. 2004. The relationship between Swiss needle cast symptom severity and level of Phaeocryptopus gaeumannii colonization in coastal Douglas-fir (Pseudotsuga menziesii var. menziesii). For. Path. 34: 383-394.

2005

Johnson, G.R., Grotta, A.T., Gartner, B.L., and G. Downes. 2005. Impact of the foliar pathogen Swiss needle cast on wood quality of Douglas-fir. Can. J. For. Res. 35: 331-339.

Mainwaring, D.B., Maguire, D.A., Kanaskie, A., and J. Brandt. 2005.Growth Responses to commercial thinning in Douglas-fir stands with varying intensity of Swiss needle cast. Can. J. For. Res. 35: 2394–2402.

Manter, D.K., Kavanagh, K. and C.L. Rose. 2005. Growth response of Douglas-fir seedlings to nitrogen fertilization: importance of Rubisco activation state and respiration rates. Tree Physiology 25: 1015–1021.

Manter, D.K., Reeser, P.W., and J.K. Stone. 2005. A climate-based model for predicting geographic variation in Swiss Needle Cast severity in the Oregon coast range. Phytopathology 95: 1256–1265.

Temel, F., Johnson, G.R., and W.T. Adams. 2005. Early genetic testing of coastal Douglas-fir for Swiss needle cast tolerance. Can. J. For. Res., 35: 521-529.

2006

Weiskittel, A.R., D.A. Maguire, S.M. Garber, and A. Kanaskie. 2006. Influence of Swiss needle cast on foliage age-class structure and vertical foliage distribution in Douglas-fir plantations in north coastal Oregon. Canadian Journal of Forest Research 36: 1497-1508.

Swiss Needle Cast Aerial Surveys, 1996 to 2006

Alan Kanaskie, Mike McWilliams, Keith Sprengel, Dave Overhulser

Survey procedures

Aerial surveys for SNC have been conducted in April and May each year since 1996. The observation plane flies at 1,500 to 2,000 feet above the terrain, following north-south lines separated by 2 miles. Observers look for areas of Douglas-fir forest with obvious yellow to yellow-brown foliage, a symptom of moderate to severe Swiss needle cast damage. Patches of forest with these symptoms (patches are referred to as polygons) are sketched onto computer touch screens displaying topographic maps or ortho-photos and the position of the aircraft.

The area surveyed extends from the coastline eastward approximately 30 miles (or until symptoms are no longer visible), and from the Columbia River south to Gold Beach. We survey approximately 2 to 3 million acres each year. We occasionally have surveyed the Cascade Range, but the low damage levels have not justify repeated surveys.

Results and discussion

The Coast Range survey was flown during the last week of April and the first week of May and covered approximately 2.95 million acres of forest. We mapped 324,584 acres of Douglas-fir forest with obvious symptoms of Swiss needle cast; 226,864 acres north of the Lincoln-Lane county line, and 97,720 acres south of the Lincoln-Lane county line (Figure 1). The easternmost area with obvious SNC symptoms was approximately 28 miles inland from the coast in the Highway 20 corridor, but the majority of area with symptoms occurred within 18 miles of the coast. Figures 2, 3 and 4 show the trend in damage from 1996 through 2006. The survey maps for 1996 through 2006 appear in figure 4.

The 2006 survey results show a marked increase in the area of forest with symptoms of Swiss needle cast compared to the previous 3 years. Survey conditions were excellent and the observers considered the 2006 survey to be the most reliable to date. Symptoms developed rapidly following a period of low temperatures in late February and warm sunny weather in April and early May.

The Swiss needle cast aerial survey provides a conservative estimate of damage because observers can map only those areas where disease symptoms have developed enough to be visible from the air. We know (from permanent plot data and ground checks) that Swiss needle cast occurs throughout the survey area, but that discoloration often is not severe enough to enable aerial detection. The total amount of forest affected by Swiss needle cast is far greater than indicated by the aerial survey. The aerial survey does, however, reasonably depicts the extent of moderate to severe damage, and coarsely documents trends in damage over time.

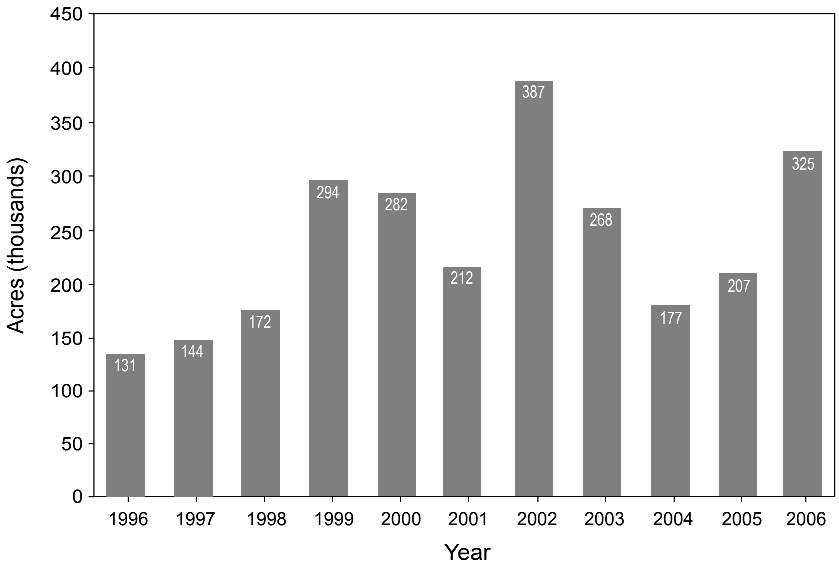


Figure 1. *Trend in area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, 1996-2006.*

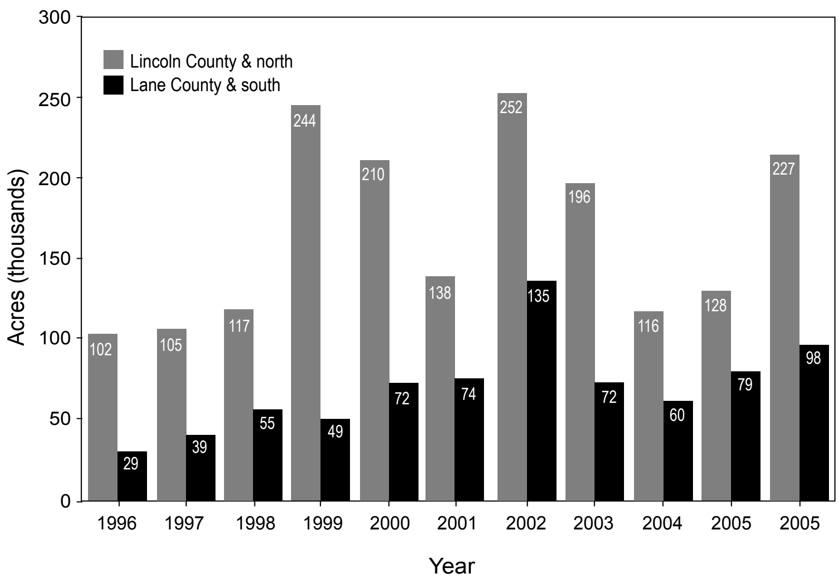


Figure 2. *Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, by zone, 1996-2006.*

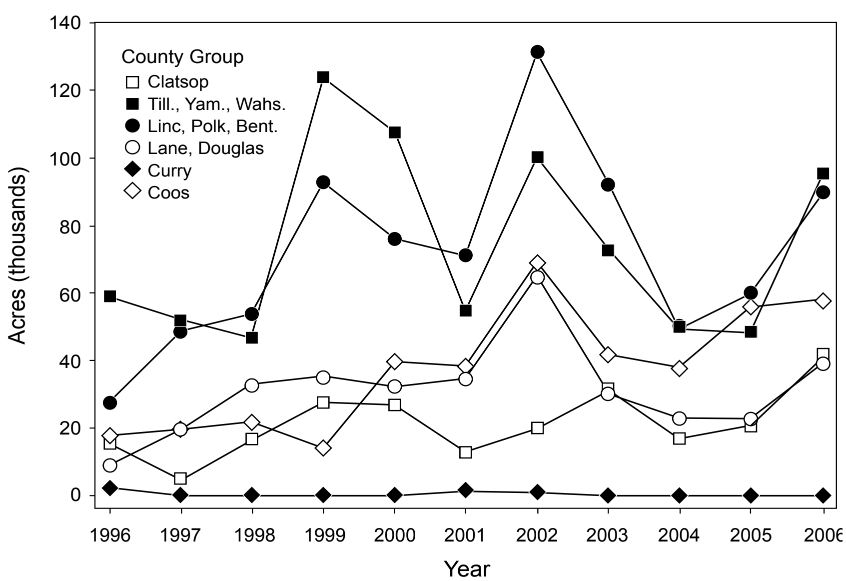


Figure 3. *Area of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial surveys in April and May, by county group, 1996-2006.*

Acknowledgments

The survey was conducted by the Oregon Department of Forestry Insect & Disease and Air Operations sections, and was funded by the Oregon State University Swiss Needle Cast Cooperative, the USDA Forest Service Forest Health Monitoring Program, and the Oregon Department of Forestry. Mike McWilliams (ODF) is the survey coordinator and primary aerial observer; Keith Sprengel (USFS), and Dave Overhulser (ODF) were additional aerial observers. Jim Baranek (ODF) piloted the plane.

Note

The GIS data and a pdf file for the SNC surveys can be accessed via the ODF web page at: http://www.odf.state.or.us/fa/FH/maps.htm

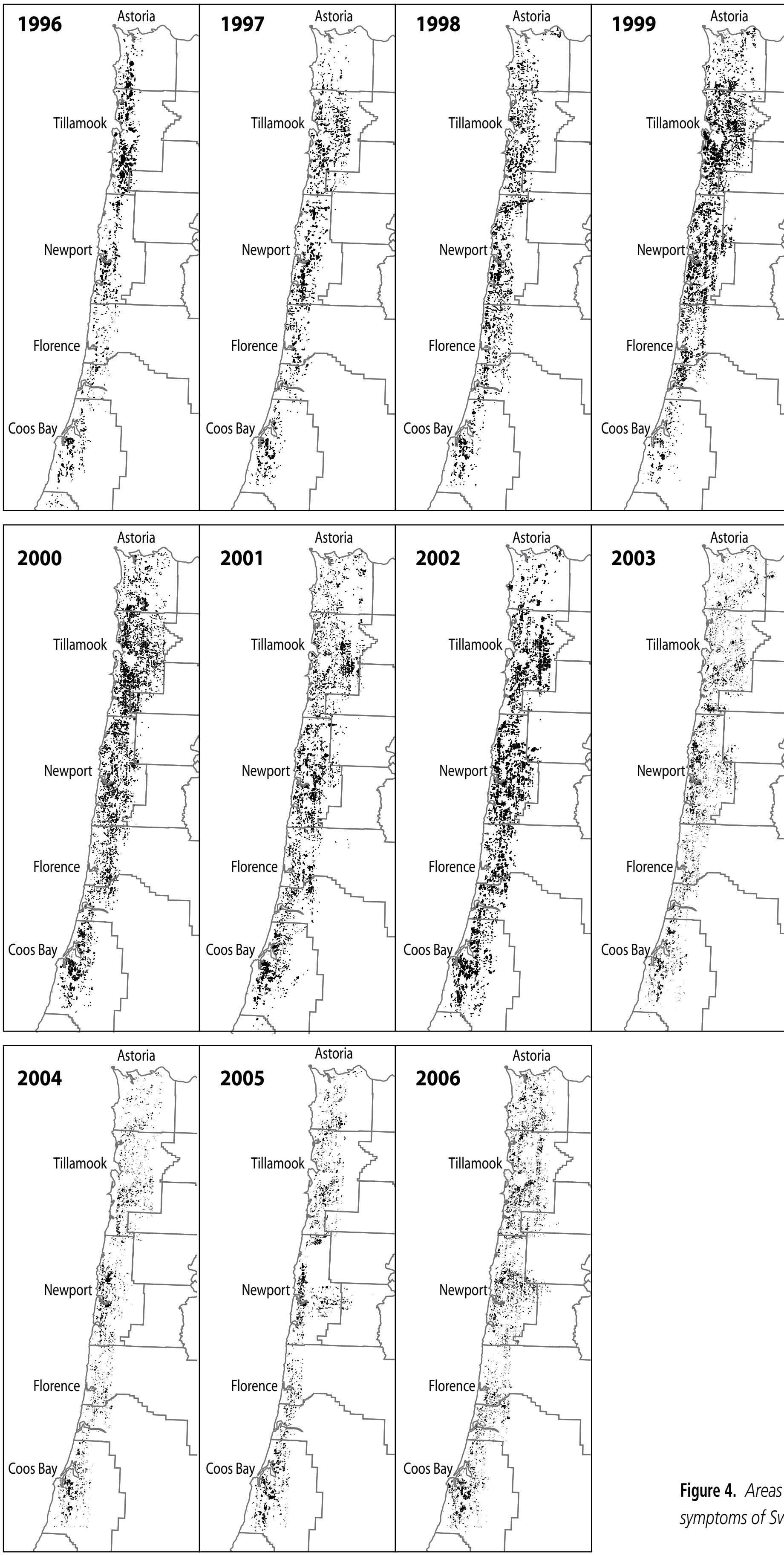


Figure 4. *Areas of Douglas-fir forest in western Oregon with symptoms of Swiss needle cast detected during aerial survey.*

Impacts of Swiss Needle Cast on Douglas-fir in the Cascade Foothills of Northern Oregon after Five Years

Greg Filip, USDA For. Serv., Portland, OR; Alan Kanaskie, Ore. Dept. of For., Salem, OR; Will Littke and John Browning, Weyerhaeuser Corp., Federal Way, WA; Diane Hildebrand, USDA For. Serv., Sandy, OR; and Doug Maguire, Oregon State Univ., Corvallis, OR

Abstract

In 2001 and 2006, we examined 590 Douglas-firs in 59 stands age 10-23 years in the northern Oregon Cascade foothills. Stands ranged in elevation from 500 to 4,200 ft., slope from 0 to 60%, and total basal area/acre from 20 to 158 ft^2. Mean 5-year-dbh growth was 2.4 in. (range = 1.2 to 3.4) and total-height growth was 11.9 ft. (range = 7.7 to 15.5). Mean needle-retention index increased by 3.4 (range = -3.4 to 11.8) over 5 years, and mid-crown retention increased by 1.2 years (range 0.2 to 2.3). Mean percentages of stomata occluded by pseudothecia were 13.6% for 2000-(2-year-old) needles and 1.7% for 2001-(1-year-old) needles sampled in 2002, and 13.3% for 2004 (2-yr-old) needles sampled in 2006. Mean crown-length to sapwood- area ratio was 5.2 cm/cm^2 and ranged from 2.3 to 9.0 in 2006. There were poor correlations (R^2 <0.3) among all variable except for stand elevation were there was a moderate correlation between stand elevation and either 2000-stomata occluded (R^2 = 0.43) or 2004-stomata occluded (R^2 = 0.50), where there was fewer pseudothecia at the higher elevations. Either five years is not enough time to evaluate the affects of Swiss needle cast on Douglas-fir growth in the Oregon Cascades or there was no significant effect of Swiss needle cast during the latest outbreak on Douglas-fir growth. Based on our results and their interpretation, forest managers may need not alter their current practices in the northern Oregon Cascades, and managing a mix of Douglas-fir and western hemlock at lower elevations and noble fir at higher elevations will help offset any future stand-growth declines due to Swiss needle cast.

Introduction

Swiss needle cast (SNC), caused by the fungus, *Phaeocryptopus gaeumannii*, is one of the most damaging diseases affecting Douglas-fir in the Pacific Northwest (Hansen et al. 2000). Biological impact is particularly acute on the Oregon and Washington Coast, one of the most productive regions for forest growth in the temperate world. In 2006, the aerial detection survey mapped 324,584 acres of Douglas-fir forest with obvious symptoms of SNC in Oregon. Annual Douglas-fir volume-growth losses from SNC are estimated at about 23% over 187,000 acres with some losses as high as 52% in NW Oregon (Maguire et al. 2002).

Although impact from SNC occurs in the northern Cascade Mountains of Oregon, it is assumed to be less than damage in the Oregon Coast Range.

In 2001, baseline monitoring plots were established in 59 stands covering 2 million acres in the Cascade Mountains in Oregon with USFS-Forest Health Monitoring funding. It was essential that these plots be re-measured in order to determine the 5-year change and biological impact of SNC on Douglas-fir growth in the Oregon Cascades. These plots are the only source of data for SNC impact in the Oregon Cascade Range.

Objectives of our project were to determine changes after 5-years (2001 to 2006) in 1) tree diameter and total-height growth, and live-crown ratio and 2) Swiss needle cast (SNC) severity as estimated by needle retention, stomata occlusion, and crown length/sapwood area ratio in 59 stands in the northern Oregon Cascade Mountains.

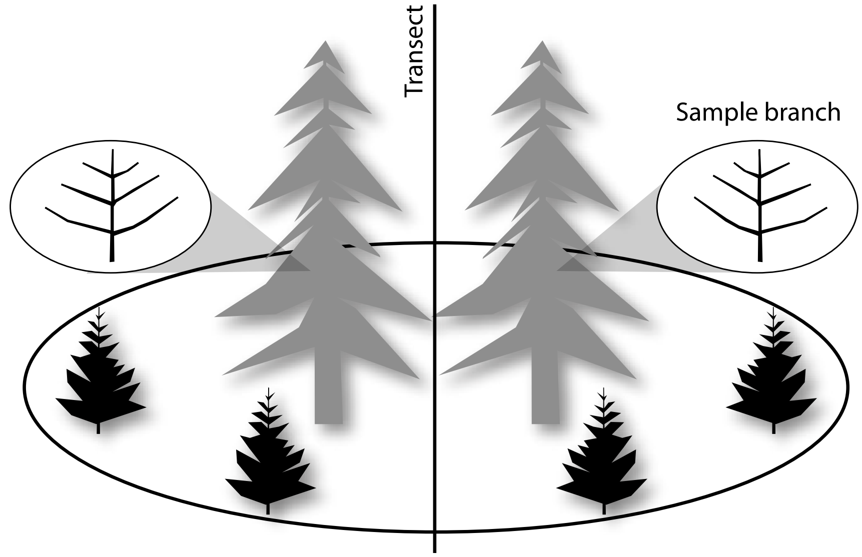


Fig. 2 Diagram of a stand plot where two dominant Douglas-firs were sampled at each of 5 plots per stand along a transect. Branches were sampled at mid-crown for foliage retention and needle occlusion associated with Swiss needle cast.

Methods

From April to June, 2001, prior to Douglas-fir budbreak, transects were installed in 59 stands according to SNCC protocols (Kanaskie and Maguire 1999). Sampled stands were 10- to 23-years old and contained more than 50% Douglas-fir. Stands were systematically located on lands administered by USDA Forest Service, USDI Bureau of Land Management, Weyerhaeuser Corp, Port Blakely Trees Farms, and Longview Fibre in the western Oregon Cascade Mountains (Freeman 2001, Fig. 1). Each stand has one transect with five sample points located at 50-foot intervals. Transects were established in a location representative of the stand. Stand data collected in 2001 included: 1) elevation, 2) slope aspect (8 cardinal points), 3) slope %, and 4) some GPS coordinates at the reference point at the start of the transect.

At each sample point, the nearest co-dominant or dominant Douglas-fir on each side of the transect was selected for a total of 10 trees per stand (Fig. 2). Sample trees were painted with a number 1 or 2, and were without damage from agents other than SNC. Data collected for each tree in 2001 included: 1) stand, point, and tree no., 2) dbh (at 4.5 ft. above ground, nearest 0.1 in.), 3) total height (nearest ft.), 4) height to lowest live branch (nearest ft.), 5) ocular estimation of foliage retention in the mid-crown (0 to 6 yrs), and 6) foliage–retention index of a sampled branch. Heights were measured with a clinometer. Live-crown ratios for each year were calculated by subtracting height to lowest live branch from total tree height to get live-crown length, and then dividing crown length by total tree height and multiplying by 100.

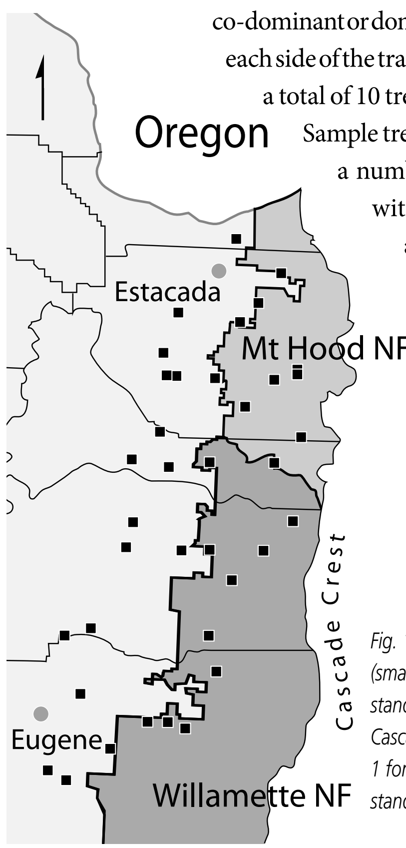


Fig. 1 Map showing locations (small squares) of 59 sampled stands in the northern Oregon Cascade foothills. See Table 1 for GPS coordinates for all stands.

Foliage-retention index was calculated for each sample tree as follows: a live branch at mid-crown was selected on the S side of the sample tree and cut from the stem with the pole pruner, if necessary. From the cut branch, a secondary lateral branch was selected, and the amount of foliage remaining in each needle age class was rated and recorded as: 0 = 0 to10% of full compliment present, 1 = 11 to 20% present, 2 = 21 to 30% present, ….9 = 90 to 100% present. Ratings were summed for a minimum score of 0 and a maximum of 36 for each branch. Needle retention has been shown to be the most reliable and efficient variable when estimating SNC severity in terms of tree volume growth loss (Filip et al. 2000, Hansen et al. 2000, Maguire et al. 2002). Needle retention as estimated from the mid-crown is considered more reliable than upper or lower crown estimates, especially in larger trees.

In 2002, 37 of the 59 stands were sampled for pseudothecia density. For 5 sample trees per stand (1 tree per plot pair), a live branch as sampled above was returned to the Weyerhaeuser Centralia laboratory for pseudothecia estimates. Pseudothecia density measured as the percentage of needle stomata occluded is a direct method of determining the presence and severity of the causal fungus of SNC. Measurements were made on the last 2 years of needles only (1-year-old and 2-year-old needles). Foliage from 10 of 37 stands was sampled for fungal DNA by Lori Winton at OSU (Freeman 2002, Winton and Stone 2004).

From April 17 to June 17, 2006, the 59 stands sampled in 2001 were relocated using reference maps, aerial photos, and, if recorded, GPS coordinates. GPS coordinates were collected for all stands at the reference point at the start of each transect. The same data as collected in 2001 were collected for each tree in the 59 stands. Each sample tree was retagged with an aluminum numbered tag and nail at dbh facing the transect. If a sample tree was dead, the cause was recorded, and a live Douglas-fir tree was selected near the dead tree. Total height, height 5 years ago, and height of the lowest live branch were measured with a laser height measurer (Laser Technology, Inc.). For three sample trees per stand, foliage from severed branches was placed in a sample bag, labeled as to stand number; and processed in the Weyerhaeuser laboratory for pseudothecial counts, which differed from the 2002 sampling. Instead of ocular counts of pseudothecia as done in 2002, sampled needles were placed under an imager connected to a laptop computer, and the percentage of stomata occluded was estimated.

Crown-length to sapwood-area ratio (CL:SA) was estimated for one tree in a plot pair (5 trees per stand). CL:SA has been shown to effectively discriminate among stands with varying degrees of SNC (Maguire and Kanaskie 2002). Variables measured to estimate 2006 CL:SA were: 1) live-crown length (as calculated above) and 2) sapwood radius at dbh. Sapwood radius (nearest mm) and tree age at dbh were measured from an increment core taken on the side of the tree facing the transect for one tree in a plot pair (5 trees per stand).

Because some stands were thinned and stand density can influence tree growth, total basal area/acre and basal area/acre of Douglas-fir were calculated around one tree at each of the five sample points. Total plot basal area was measured around each sample tree by counting all in-trees with a prism and multiplying by the BAF=10. Only trees ≥1.0 in. dbh and all tree species including hardwoods were counted.

All data were entered into an Excel spreadsheet where R^2 values were calculated from selected graphed data.

Results and Discussion

We sampled 590 Douglas-firs in 59 stands from April 17 to June 17, 2006. Numbers of sampled stands by management agency were: Salem BLM = 16; Willamette NF = 12; Weyerhaeuser = 9; Mt. Hood NF = 7; Eugene BLM = 6; Port Blakely = 6; Longview Fibre = 2; and Ore. Dept. For. = 1. Stands ranged in elevation from 500 to 4,200 ft. and % slope from 0 to 60 (Table 1). Total basal area (ft^2) per acre averaged 79 with a range of 20 to 158. Some stands had been precommercially thinned either before or after initial plot establishment in 2001. Some plot trees were accidentally felled, and these were replaced with other trees in 2006. Douglas-fir basal area (ft^2) per acre averaged 70 with a range of 20 to 158. Other stand species included western hemlock at the lower elevations and noble fir at the upper elevations.

Mean 5-year-dbh growth was 2.4 in. (range = 1.2 to 3.4) and total-height growth was 11.9 ft. (range = 7.7 to 15.5, Table 2). Mean live-crown ratio (LCR) decreased by 9.1% (range = 3.7 to -28.0) over 5 years, but 7 of 43 (16%) stands increased in mean LCR. Sixteen trees were not measured for LCR in 2001. Although the trend was for tree growth to increase with decreasing stand density, correlations were poor for both 5-year-dbh growth ($R^2 = 0.05$) and total-height growth ($R^2 = 0.02$). Recently thinned stands (lower basal areas) may not have had enough time to show any density-reducing effect. Also, diameter growth has been shown to substantially increase with precommercial thinning, but height growth of young Douglas-fir was independent of stand density for the ranges tested (50-275 ft^2/ac) (Tappeiner et al. 1982).

Mean needle-retention index increased by 3.4 (range = -3.4 to 11.8) over 5 years, and mid-crown–foliage retention increased by 1.2 years (range 0.2 to 2.3). In 2006, many trees had a partial fifth-year and some a partial sixth-year complement of needles, but these were not reflected in retention indexes that score only the last 4 years of needles. Mid-crown-retention ratings did capture 5 and 6-year needles. Needle retention in healthy Douglas-fir does not increase with tree age, at least over a relatively short period (5 years), so the observed increase is probably due to decreasing defoliation by SNC.

Mean percentages of stomata occluded by pseudothecia were 13.6% for 2000-(2-year-old) needles and 1.7% for 2001-(1-year-old) needles sampled in 2002, and 13.3% for 2004-(2-year-old) needles sampled in 2006. There was a poor correlation between the 2001-foliage retention and percentage of 2000-needle (2-year-old) stomata occluded ($R^2 = 0.15$, Fig. 3) and 2001-needle (1-year-old) stomata occluded

($R^2 = 0.03$). Correlation between 2006-foliage retention and 2004-(2-year-old) needle stomata occlusion was slightly better ($R^2 = 0.22$). In the Oregon Coast Range, Hansen et al. (2000) showed that increasing proportions of stomata occupied by pseudothecia were associated with increasing defoliation. They recorded, however, mean pseudothecia densities up to 50% in 1-year-old foliage and foliage retention as low as 1 year, whereas our highest mean pseudothecia density was 11% in 1-year-old needles and our lowest mean foliage retention was 2.3 years. All pseudothecia collected in the Cascade Range in 2002 were from lineage 1 (Winton and Stone 2004).

There was a moderate correlation between stand elevation and 2000-stomata occlusion ($R^2 = 0.42$) or 2004-stomata occlusion ($R^2 = 0.50$), where there were fewer pseudothecia at the higher elevations (Fig. 4). Although correlations were poor ($R^2 = 0.14$ for 2001 and 0.21 for 2006), the trend was for foliage retention to also increase with elevation. Correlations between slope percent and either 2000-stomata occluded ($R^2 = 0.25$) or 2004-stomata occluded ($R^2 = 0.14$) were poor with occlusion decreasing with slope percent. Correlations between slope percent and either 2001-foliage retention ($R^2 = 0.14$) or 2006-foliage retention ($R^2 = 0.05$) were also poor but with foliage retention increasing slightly with slope.

Crown-length to sapwood-area ratio at dbh (CL:SA) averaged 5.2 cm/cm^2 (range 2.3 to 9.0) in 2006. Higher CL:SA values usually indicate poorer-growing stands; however, all of the Cascade stands sampled were in the lower range of CL:SA values for coastal Douglas-fir stands age 3.3 to 28.3 years that range from 3 to 24 CL:SA at crown base (Maguire and Kanaskie 2002) and for commercially thinned coastal Douglas-fir age 28-69 years that ranged from 4.6 to 18.1 CL:SA (Mainwaring et al. 2005). Although the trend was higher CL:SA values with poorer growing Cascade stands, correlations were poor with both 5-year-dbh growth ($R^2 = 0.04$) and total-height growth ($R^2 = 0.05$). There were also poor correlations between 2006 CL:SA and 2001-foliage retention ($R^2 = 0.003$), 2006-foliage retention ($R^2 = 0.02$), 2000-stomata occluded ($R^2 = 0.20$), or 2004-stomata occluded ($R^2 = 0.18$) .

There were poor correlations between 2001-foliage retention and 5-year-dbh growth ($R^2 = 0.02$, Fig. 5) and total-height growth ($R^2 = 0.01$, Fig. 6),

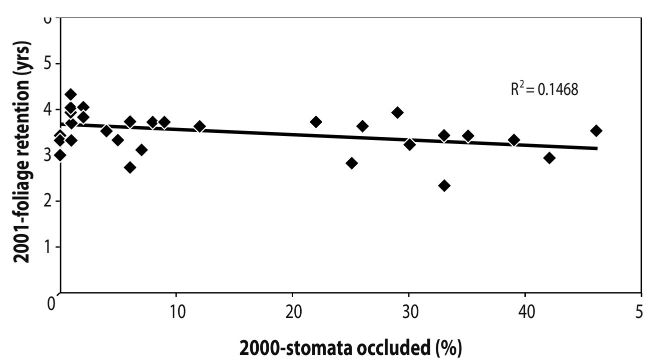


Fig. 3 Graph showing correlation between the number of years of 2001-foliage retention at mid-crown and the percentage of 2000-(2-year-old) needles occluded by pseudothecia of Phaeocryptopus gaeumannii.

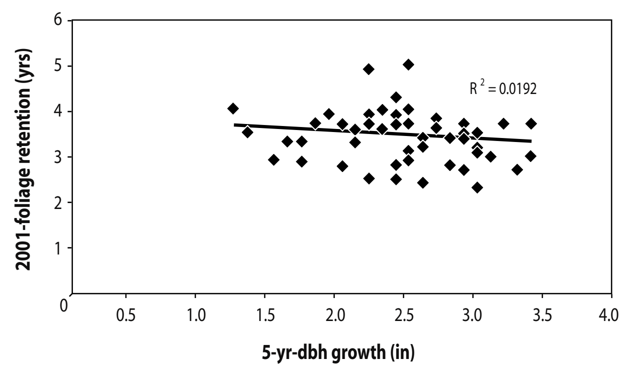


Fig. 5 Graph showing correlation between the number of years of 2001-foliage retention at mid-crown and 5-year-dbh growth of Douglas-fir from 2001 to 2006.

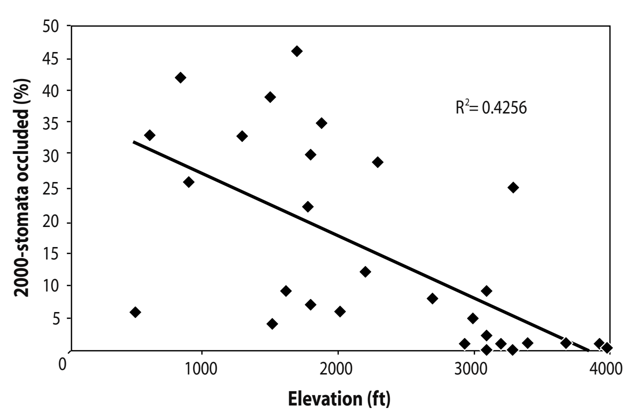


Fig. 4 Graph showing correlation between the percentage of 2000-(2-year-old) needles occluded by pseudothecia of Phaeocryptopus gaeumannii and mean stand elevation. Pseudothecia decreased with increasing elevation.

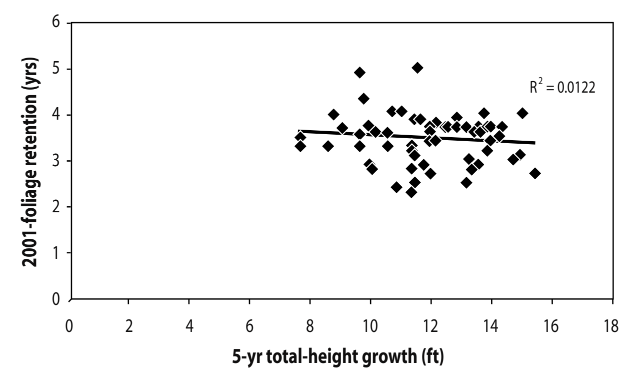


Fig. 6 Graph showing correlation between the number of years of 2001-foliage retention at mid-crown and 5-year total-height growth of Douglas-fir from 2001 to 2006.

between 2000-stomata occluded and 5-year-dbh growth ($R^2 = 0.02$) and total-height growth ($R^2 = 0.03$), and between 2004-stomata occluded and 5-year-dbh growth ($R^2 = 0.02$) and total-height growth ($R^2 = 0.04$). Either five years is not enough time to evaluate the affects of Swiss needle cast on Douglas-fir dbh growth in the Oregon Cascades, or there was no significant effect of Swiss needle cast on Douglas-fir growth during the latest outbreak.

Conclusions

There are at least two possible reasons why there may be no appreciable affect of Swiss needle cast on Douglas-fir 5-year-diameter and height growth during the latest SNC outbreak in the Cascade Range:

1) Oregon Cascade Range site characteristics, including plant associations, soil chemistry and parent material, air temperatures, and monthly precipitation and leaf wetness, may not be as conducive to elevated populations of the causal fungus, *Phaeocryptopus gaeumannii,* and subsequent severe defoliation, as in the Coast Range.

2) The genetics (lineage 1) of isolates of the causal fungus, , in the Oregon Cascades more closely resemble isolates from Idaho, Europe, and New Zealand than isolates from the Oregon Coast Range (Winton and Stone 2004). Also, lineage 2, which is abundant in the Oregon Coast Range, has not been reported in the Cascade Mountains.

Based on our results and their interpretation, forest managers may need not alter their current practices in the northern Oregon Cascades, and managing a mix of Douglas-fir and western hemlock at lower elevations and noble fir at higher elevations will help offset any future stand-growth declines due to Swiss needle cast or other pest outbreaks. On the other hand, we report are only 5-year results, and more time may be needed to adequately detect any significant effects from Swiss needle cast in the Cascade Range. Plans are to resample Cascade stands in 5 years (2011).

Acknowledgements

We thank Mike McWilliams, Oregon Dept. of Forestry; Floyd Freeman, USDA Forest Service; and Bob Ohrn and Charlie Thompson, Salem BLM. We also thank Jon Laine, Kevin Nelson, and Michael Thompson from ODF, and the field crews from the Salem and Eugene BLM and the Mt. Hood and Willamette NF's for data collection.

Literature Cited

Filip, G.M., A. Kanaskie, K. Kavanagh, G. Johnson, R. Johnson, and D. Maguire. 2000. Silviculture and Swiss needle cast: research and recommendations. For. Res. Lab, Res. Contribution 30, Oregon State Univ., Corvallis. 16p.

Freeman, F. 2001. Swiss needle cast monitoring transects in the Oregon Cascades. P. 11-13 *in* Swiss Needle Cast Cooperative annual report. Filip, G. (ed.), College of Forestry, Oregon State Univ., Corvallis. 98p.

Freeman, F. 2002. Swiss needle cast monitoring in the Oregon Cascades. P. 11-14 *in* Swiss Needle Cast Cooperative annual report. Filip, G. (ed.), College of Forestry, Oregon State Univ., Corvallis. 86p.

Hansen, E.M., J.K. Stone, B.R Capitano, P. Rosso, W. Sutton, L. Winton, A. Kanaskie, and M.G. McWilliams. 2000. Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in Coastal Oregon. Plant Disease 84:773-778.

Kanaskie, A. and D. Maguire. 1999. Field specifications and manual for rating Swiss needle cast in Douglas-fir. Oregon Department of Forestry publication, Salem, OR.

Maguire, D. and A. Kanaskie. 2002. The ratio of live crown length to sapwood area as a measure of crown sparseness. Forest Science 48(1):93-100.

Maguire, D., A. Kanaskie, W. Voelker, R. Johnson, and G. Johnson. 2002. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. West. J. Appl. For. 17(2):86-95.

Mainwaring, D.B., D.A. Maguire, A. Kanaskie, and J. Brandt. 2005. Growth responses to commercial thinning in Douglas-fir stands with varying severity of Swiss needle cast in Oregon, USA. Can. J. For. Res. 35:2394-2402.

Tappeiner, J.C., J.F. Bell, and J.D. Brodie. 1982. Response of young Douglas-fir to 16 years of intensive thinning. Res. Bull. 38, For. Res. Lab, Oregon State Univ., Corvallis. 17p.

Winton, L.M. and J.K. Stone. 2004. Microsatellite population structure of *Phaeocryptopus gaeumannii* and pathogenicity of *P. gaeumannii* genotypes/lineages. P. 42-48 *in* Swiss Needle Cast Cooperative annual report. Mainwaring, D. (ed.), College of Forestry, Oregon State Univ., Corvallis. 97p.

Table 1. Characteristics of 59 Douglas-fir stands sampled for Swiss needle cast in 2006 in the western Oregon Cascade foothills. Age and basal-area means are from 5 trees per stand.

Stand no.	Management agency	GPS coordinates[1] (N)	(W122)	Elev. (ft)	Aspect	Slope (%)	Mean BH age (yr)	Total BA (ft^2/ac)	D-fir BA (ft^2/ac)
1	Pt. Blakely	45.12.236	21.565	1100	S	10	18	74	64
2	Pt. Blakely	45.11.066	16.599	1850	SW	20	12	30	28
3	Pt. Blakely	45.10.850	16.388	2300	NW	12	12	96	64
4	Pt. Blakely	45.11.827	17.542	1400	Flat	0	12	112	108
5[2]	Weyerhaeuser	45.05.550	18.793	3100	SW	15	12	20	18
6	Salem BLM	45.07.633	22.301	2000	SW	35	10	44	42
7	Pt. Blakely	45.09.872	21.211	1800	SW	35	17	90	84
8	Salem BLM	45.09.097	15.629	3200	SE	35	12	56	46
9	Longview	44.69.644	71.793	650	NE	-	18	84	82
10	Weyerhaeuser	44.41.282	38.248	1500	NW	-	11	76	54
11	Weyerhaeuser	44.39.379	42.285	1250	SW	-	20	126	126
12	Weyerhaeuser	44.37.916	41.309	1100	N	15	18	118	116
13	Salem BLM	44.36.928	41.268	1200	SW	35	12	64	46
14	Salem BLM	44.35.831	39.006	1200	SW	50	21	110	100
15	Mt. Hood NF	45.06.493	15.974	3150	NW	30	14	76	58
16	Salem BLM	44.38.590	38.046	2500	SW	20	13	42	42
17	Salem BLM	44.34.919	40.285	1200	NW	40	18	100	96
18	Salem BLM	44.33.596	40.459	1400	SW	20	22	70	60
19	Weyerhaeuser	44.32.189	42.046	800	W	20	11	94	90
20	Weyerhaeuser	44.31.624	41.333	1100	Flat	0	14	142	136
21	Weyerhaeuser	44.31.308	41.487	1050	NW	-	14	158	158
22	Salem BLM	44.29.983	40.633	1300	SW	-	19	86	86
23	Pt. Blakely	45.14.697	50.119	500	-	-	11	68	68
24	Longview	45.15.305	10.937	1800	-	-	11	78	72
25	Salem BLM	45.16.304	27.293	900			20	140	140
27	Salem BLM	45.29.743	12.356	1300	NW	20	17	130	88
28	Ore Dept. For.	44.49.279	37.565	1800	SW	12	12	98	70
29	Salem BLM	-	-	1700	NW	25	17	124	124
30	Weyerhaeuser	45.05.078	28.721	600	Flat	0	12	34	32
31	Weyerhaeuser	45.04.616	27.001	1500	NW	15	19	94	86
32	Salem BLM	44.38.098	36.791	3100	SW	20	13	60	48
33	Salem BLM	44.33.631	38.299	2300	E	15	18	114	110
34	Salem BLM	44.33.329	23.460	3400	N	50	17	138	80
35	Salem BLM	45.04.172	17.467	3100	SW	60	14	80	74
36	Salem BLM	44.54.634	30.829	2700	NE	15	18	94	80
37	Eugene BLM	44.18.363	46.027	1510	SW	10	14	60	60
38	Eugene BLM	44.17.199	53.277	2013	S	60	13	80	80
39	Eugene BLM	44.11.084	81.656	835	NW	15	14	60	60
40	Eugene BLM	43.52.366	56.232	1622	NW	20	12	52	52
41	Eugene BLM	43.56.724	40.226	1875	S	20	14	78	72
42	Eugene BLM	43.51.064	51.049	1782	W	10	16	94	92
43	Mt. Hood NF	45.23.678	00.108	2940	W	-	13	96	64
44	Mt. Hood NF	45.18.784	05.209	2680	SW	-	17	68	56
45	Mt. Hood NF	45.06.030	55.397	2760	W	-	13	54	54
46	Mt. Hood NF	45.04.647	01.219	1960	NE	-	16	70	50
47	Mt. Hood NF	44.59.709	08.543	4200	SW	-	11	74	74
48	Mt. Hood NF	-	-	3000	NE	-	16	62	54
52	Willamette NF	44.48.914	17.300	4000	SE	60	16	48	36
53	Willamette NF	44.49.714	00.867	4050	NW	30	12	60	46
54	Willamette NF	44.41.257	14.347	3000	NE	40	17	70	70
55	Willamette NF	44.38.816	55.665	3100	W	15	12	32	28
56	Willamette NF	44.32.946	16.090	3400	W	55	16	52	48
57	Willamette NF	44.33.479	02.234	3950	S	20	13	42	34
58	Willamette NF	44.28.401	10.223	3300	SE	10	12	56	56
59	Willamette NF	44.17.747	16.776	3700	S	40	13	38	36
60	Willamette NF	44.19.653	23.013	2200	SE	20	18	100	98
61	Willamette NF	44.02.171	31.118	3300	NW	20	10	32	32
62	Willamette NF	44.02.388	26.280	3200	SE	55	10	20	20
63	Willamette NF	44.01.191	21.563	3100	NW	60	15	35	30
Mean				2137		26.6	14.6	79	70

[1] GPS coordinates are for the reference point at the start of the stand transect.
[2] Data from stand 5 were not used in mean calculations because of severe defoliation not associated with Swiss needle cast.
[3] Data from stand 56 were not used in mean calculations because 6 new trees were selected in 2002 when part of the transect was moved.

Table 2. Changes in 5-year growth and live-crown ratio and 2006 crown-length to sapwood-area ratio (CL:SA) for 59 stands sampled for Swiss needle cast in 2001 and 2006 in the western Oregon Cascade foothills. Means are from 10 trees per stand except for CL:SA when 5 trees per stand were sampled.

Stand no.	Dbh (in.)			Total height (ft)			Live-crown ratio (%)			2006CL:SA1
	2001	2006	growth	2001	2006	growth	2001	2006	change	(cm/cm²)
1	8.6	10.9	2.3	43.9	54.5	10.6	88.8	71.2	-17.6	2.8
2	3.5	6.1	2.6	19.5	30.9	11.4	94.9	96.8	+1.9	6.1
3	4.2	6.9	2.7	25.4	39.1	13.7	94.1	83.8	-10.3	6.8
4	6.5	8.0	1.5	39.3	49.3	10.0	86.4	67.5	-18.9	4.8
5[2]	2.3	3.4	1.1	13.5	18.5	5.0	92.5	94.5	+2.0	12.3
6	2.3	4.3	2.0	15.5	25.6	10.1	93.4	89.8	-3.6	9.0
7	7.3	10.0	2.7	40.0	52.0	12.0	94.1	88.4	-5.7	4.2
8	4.2	7.1	2.9	23.7	36.2	12.5	94.3	92.2	-2.1	4.8
9	8.7	11.3	2.6	44.2	55.1	10.9	-	68.5	-	3.0
10	4.1	7.5	3.4	23.5	38.3	14.8	-	87.0	-	4.8
11	7.8	9.5	1.7	54.3	66.1	11.8	-	53.4	-	4.2
12	9.1	11.3	2.2	52.5	64.0	11.5	76.2	58.7	-17.5	3.9
13	3.8	6.7	2.9	21.6	37.1	15.5	92.0	87.9	-4.1	5.9
14	10.2	12.5	2.3	53.3	68.4	15.1	85.3	62.9	-22.4	3.3
15	5.8	9.2	3.4	31.1	43.1	12.0	94.7	92.9	-1.8	4.9
16	4.0	6.5	2.5	24.9	36.4	11.5	92.9	89.6	-3.3	5.6
17	7.7	10.2	2.5	43.5	57.4	13.9	88.5	68.5	-20.0	4.4
18	9.3	11.8	2.5	45.1	56.2	11.1	93.4	88.8	-4.6	4.2
19	3.9	6.3	2.4	24.0	37.2	12.2	93.1	75.0	-18.1	6.3
20	6.3	8.3	2.0	37.3	50.5	13.2	87.7	64.7	-23.0	4.1
21	6.8	9.0	2.2	38.8	51.7	12.9	87.1	59.1	-28.0	3.0
22	8.4	11.2	2.8	42.0	55.4	13.4	91.9	87.1	-4.8	3.8
23	3.7	7.0	3.3	21.2	33.2	12.0	-	86.5	-	5.2
24	4.0	7.0	3.0	23.7	38.7	15.0	92.9	88.4	-4.5	5.9
25	9.7	11.8	2.1	55.9	66.1	10.2	78.2	50.5	-27.7	2.3
27	6.6	9.4	2.8	40.5	52.7	12.2	82.5	64.6	-17.9	3.1
28	4.1	7.1	3.0	24.4	38.3	13.9	93.9	83.8	-10.1	5.9
29	7.1	10.1	3.0	45.2	54.9	9.7	93.7	82.2	-11.5	3.5
30	3.9	6.9	3.0	21.8	33.2	11.4	91.1	82.7	-8.4	5.3
31	7.1	8.7	1.6	42.5	53.9	11.4	90.3	75.5	-14.8	5.1
32	5.0	7.7	2.7	27.9	40.1	12.2	95.6	87.4	-8.2	5.2
33	7.9	9.8	1.9	45.2	56.7	11.5	89.8	70.2	-19.6	4.2
34	3.9	5.1	1.2	24.9	33.7	8.8	84.2	73.5	-10.7	6.0
35	5.7	8.2	2.5	31.1	41.9	10.8	95.6	91.5	-4.1	5.7
36	6.0	7.8	1.8	35.9	48.5	12.6	86.0	75.0	-11.0	5.6
37	5.0	7.9	2.9	28.4	42.7	14.3	-	84.4	-	4.5
38	5.3	8.2	2.9	30.8	45.2	14.4	-	89.7	-	5.3
39	4.1	6.6	2.5	25.2	38.8	13.6	-	83.6	-	5.7
40	3.4	5.9	2.5	21.1	34.0	12.9	-	77.1	-	6.6
41	5.1	7.7	2.6	29.0	43.0	14.0	-	81.5	-	5.2
42	6.9	10.1	3.2	37.1	51.1	14.0	-	84.1	-	3.4
43	4.2	6.5	2.3	22.7	36.5	13.8	-	85.7	-	6.2
44	4.5	5.8	1.3	26.2	33.9	7.7	-	81.5	-	6.7
45	4.4	6.8	2.4	24.6	34.4	9.8	-	95.7	-	6.8
46	4.5	7.0	2.5	28.2	39.8	11.6	-	82.7	-	5.3
47	3.0	5.1	2.1	15.5	26.1	10.6	-	95.3	-	6.7
48	4.5	6.7	2.2	25.3	35.0	9.7	-	93.4	-	5.8
52	4.4	6.0	1.6	22.4	31.0	8.6	91.8	94.3	+2.5	6.0
53	3.6	6.0	2.4	17.5	29.2	11.7	91.1	92.2	+1.1	5.1
54	5.6	7.3	1.7	31.8	41.5	9.7	89.4	87.6	-1.8	5.5
55	3.4	6.3	2.9	18.9	30.9	12.0	92.4	96.1	+3.7	5.3
56	-	5.5	-	20.8	28.1	7.3	-	87.6	-	6.1
57	4.4	6.9	2.5	19.5	29.5	10.0	93.3	96.6	+3.3	3.9
58	4.3	6.7	2.4	23.5	34.9	11.4	94.6	91.6	-3.0	6.6
59	3.2	4.8	1.6	17.9	25.6	7.7	93.8	92.6	-1.2	8.3
60	6.7	9.0	2.3	37.0	50.5	13.5	93.4	80.1	-13.3	3.8
61	2.8	5.9	3.1	15.8	29.1	13.3	99.0	95.7	-3.3	6.6
62	2.8	5.0	2.2	17.4	26.5	9.1	99.4	95.3	-4.1	8.1
63	4.1	6.5	2.4	23.1	36.7	13.6	94.7	92.0	-2.7	6.7
Mean	5.4	7.8	2.4	30.6	42.5	11.9	91.1	82.0	-9.1	5.2

[1] Sapwood area was calculated at breast height (4.5 ft). Higher mean CL:SA values indicate poorer-growing stands.

[2] Data from stand 5 were not used in mean calculations because of severe defoliation not associated with Swiss needle cast.

[3] Data from stand 56 were not used in mean calculations because 6 new trees were selected in 2002 when part of the transect was moved.

Table 3. Changes in 4-year needle-retention index and mean mid-crown foliage retention, and percentages of occluded stomata for stands sampled for Swiss needle cast in 2001, 2002, and 2006 in the western Oregon Cascade foothills. Means are from 10 trees per stand except for 2000-1 stomata where 5 trees per stand were sampled and 2004 stomata where 3 trees per stand were sampled.

Stand no.	Foliage retention index (0-36)			Mid-crown foliage retention (yrs)			Needle-stomata occluded (%)		
	2001	2006	Change	2001	2006	Change	2000	2001	2004
1	32.3	33.4	1.1	3.6	4.5	0.9	-	-	43
2	29.2	35.4	6.2	3.2	4.5	1.3	-	-	0
3	33.0	35.6	2.6	3.6	4.5	0.9	-	-	10
4	26.0	33.0	7.0	2.9	3.7	0.8	-	-	29
5	27.4	18.6	-8.8	3.0	1.9	-1.1	-	-	4
6	26.8	36.0	9.2	2.8	4.7	1.9	-	-	3
7	32.6	36.0	3.4	3.6	4.7	1.1	-	-	18
8	34.0	35.8	1.8	3.7	4.4	0.7	-	-	0
9	23.1	34.3	11.2	2.4	3.6	1.2	-	-	40
10	27.8	34.1	6.3	3.0	4.6	1.6	-	-	17
11	26.4	-	-	2.9	4.2	1.3	-	-	-
12	24.2	36.0	11.8	2.5	4.1	1.6	-	-	20
13	24.5	35.9	11.4	2.7	4.4	1.7	-	-	35
14	34.2	36.0	1.8	4.0	4.2	0.2	-	-	16
15	33.2	35.8	2.6	3.7	5.2	1.5	-	-	1
16	27.7	35.8	8.1	3.1	4.7	1.6	-	-	12
17	35.4	32.0	-3.4	3.7	4.1	0.4	-	-	22
18	32.8	36.0	3.1	4.0	4.9	0.9	-	-	1
19	22.9	31.9	9.0	2.5	3.7	1.2	-	-	43
20	33.8	35.1	1.3	3.7	5.1	1.4	-	-	9
21	34.7	-	-	3.9	4.6	0.7	-	-	36
22	25.8	35.2	9.4	2.8	4.3	1.5	-	-	37
23	26.1	35.8	9.7	2.7	5.0	2.3	6	3	10
24	29.2	35.6	6.4	3.1	4.8	1.7	7	1	39
25	32.8	-	-	3.6	4.3	1.0	26	4	25
27	31.5	31.7	0.2	3.4	4.4	1.0	33	8	12
28	29.1	35.3	6.2	3.2	4.2	1.0	30	2	20
29	29.1	36.0	6.9	3.5	5.6	2.1	46	1	49
30	21.0	31.6	10.6	2.3	3.4	1.1	33	11	43
31	30.3	34.9	4.6	3.3	4.5	1.2	39	2	34
32	34.3	36.0	1.7	3.8	5.3	1.5	2	0	4
33	33.0	35.3	2.3	3.9	4.5	0.6	29	6	24
34	34.2	33.3	-0.9	4.0	5.0	1.0	1	0	3
35	33.8	35.7	1.9	4.0	4.7	0.7	2	0	2
36	33.0	34.8	1.8	3.7	5.0	1.3	8	2	4
37	29.7	36.0	6.3	3.5	5.1	1.6	4	0	17
38	30.2	35.4	5.2	3.7	5.0	1.3	6	1	6
39	27.1	36.0	8.9	2.9	4.5	1.6	42	2	22
40	32.4	35.9	3.5	3.7	4.9	1.2	9	2	6
41	30.1	34.5	4.4	3.4	4.3	0.9	35	3	5
42	28.3	36.0	7.7	3.7	4.7	1.0	22	1	11
43	30.2	36.0	5.8	4.0	4.5	0.5	1	0	0
44	26.5	30.9	4.4	3.5	3.8	0.3	-	-	14
45	34.1	36.0	1.9	4.3	5.5	1.2	1	0	1
46	33.3	35.0	1.7	5.0	5.5	0.5	-	-	15
47	32.0	35.9	3.9	3.3	5.1	1.8	-	-	1
48	33.3	36.0	2.7	4.9	6.1	1.2	-	-	1
52	29.5	33.3	3.8	3.3	4.3	1.0	0	0	1
53	34.8	36.0	1.2	3.9	5.5	1.6	1	0	1
54	27.2	35.7	8.5	3.3	4.9	1.6	5	1	1
55	31.8	36.0	4.2	3.4	5.2	1.8	0	0	1
56	32.4	36.0	3.6	4.2	5.6	1.4	1	0	0
57	35.3	35.9	0.6	3.7	4.8	1.1	1	0	0
58	23.9	34.0	10.1	2.8	4.1	1.3	25	4	6
59	29.4	35.7	6.3	3.3	5.1	1.8	1	0	2
60	31.1	35.9	4.8	3.6	5.1	1.5	12	1	3
61	31.8	36.0	4.2	3.0	4.8	1.8	0	0	0
62	33.1	35.4	2.3	3.7	4.7	1.0	1	0	0
63	32.7	36.0	3.3	3.7	5.3	1.6	9	0	4
Mean	30.2	35.0	4.8	3.4	4.6	1.2	13.6	1.7	13.3

[1] Data from stand 5 were not used in mean calculations because of severe defoliation not associated with Swiss needle cast.
[2] Living branches were too high in 2006 to sample with a pole pruner.
[3] Data from stand 56 were not used in mean calculations because 6 new trees were selected in 2002 when part of the transect was moved.

Development of a Swiss Needle Cast Module for ORGANON

Sean Garber, Douglas Maguire, Douglas Mainwaring, and David Hann

College of Forestry, Oregon State University, Corvallis, OR USA 97330

Introduction

Swiss needle cast (SNC) causes significant losses in individual tree growth, and these losses are directly proportional to symptom severity (Maguire et al. 1998; Kanaskie et al. 2002; Maguire et al. 2002a,b). The only way available at present to adjust growth predictions from models like ORGANON has been to multiply stand-level predictions by ratios of observed to expected growth, conditional on initial SNC severity for the subject stand. These stand-level computations, while providing a rough estimation of growth losses, are of limited utility when estimating SNC impacts on the growth and future dimensions of individual trees, making economic analysis and biological assessments difficult. Sufficient data have now accumulated that it is possible to develop an ORGANON module that estimates growth multipliers for individual Douglas-fir trees (Kanaskie et al. 2002, Maguire et al. 2002b, Mainwaing et al. 2004). The goal of this study was to develop equation for estimating modifiers (ranging from 0 to 1) that adjust ORGANON diameter growth equations commensurate with initial SNC severity.

Methods

Data were from all 76 Growth Impact Study (GIS) plots, control plots from the 23 Precommercial Thinning (PCT) installations, control plots from the 30 paired Commercial Thinning (CT), and 22 plots from the Retrospective Commercial Thinning plots (RCT). The GIS and PCT plots had three two-year growth periods; the CT plots had one or two two-year growth periods, and the RCT plots has one four-year growth period.

Predictor variables representing tree, stand, and site characteristics currently used in ORGANON as predictor variables were determined. Plot basal area per acre (BAL) in trees larger than the subject tree was calculated for each tree and each time period (Hann et al. 2003). Stand characteristics included the plot basal area per acre (BA). Site characteristics included site index (SI, Bruce 1981) and needle retention (NR, years), a SNC severity index. Site index was assumed to be unchanged over the growth remeasurement periods. Swiss needle cast severity was determined for each plot by averaging the visual estimations of foliage retention on each crown on each of ten trees per plot at the beginning of each growth period.

Observed periodic change in diameter (ΔDobs) was determined for each of the two-year periods for the GIS, PCT, and CT plots and the one four-year period for the RCT plots. Expected periodic change in diameter (ΔDpred) was estimated with ORGANON for each tree using the Stand Management Cooperative variant with default settings. To get ΔDpred, the growth expectations were multiplied by 0.4 for the GIS, PCT, and CT plots and 0.8 for the RCT plots. The diameter growth modifier (DMOD) was calculated as ΔDobs/ ΔDpred.

Since the modifier was expected to range between 0 and 1 and, based on previous work, be a nonlinear monotonic function of NR, the general nonlinear function explored was a three parameter Weibull function:

$$DMOD = b_0[1.0 - \exp(b_1 NR)] \qquad [1]$$

where b_0 represents the asymptote and b_1 is the rate of decrease in the modifier value with decreasing NR. The asymptote was expected to be one while b_1 was expected to be negative.

Results

Plot fractional breast height ages ranged from 5.7 to 62.5 years while Douglas-fir site index (base age 50 years) ranged from 80.4 to 212.9 (Table 1). Average plot needle retention averaged 2.6 and ranged from 1.1 to 4.6.

Individual tree modifiers (DMOD) were highly variable, ranging between 0 and 33. Over 90% of the trees were between 0 and 2 where DMOD was distributed approximately normal. Despite this variation, there was a general trend of decreasing average DMOD with decreasing NR (Fig. 1). Variation in the average line was greatest at the limits of the needle retention range. The curve of the fitted Eq. [1] displays the smooth trend and follows the average line closely, especially in the middle of the needle retention range. Residuals of the fit were well distributed with a few positive outliers. No patterns were identifiable with stand or tree level variables with the exception of a slight negative bias at large SI's and positive bias at low CR's and high BAL's (Fig. 2).

Discussion

The diameter growth modifier presented here was consistent with those patterns observed on previous stand-level analyses of growth impact (Maguire et al. 1998; Kanaskie et al. 2002; Maguire et al. 2002a,b). Equation [1] suggests that individual tree diameter growth impact, on average, does not drop below 90% until plot average needle retentions are below 3.0 years. Beyond this point, the impact increases dramatically from 88% at 2.5 years of needles to 82% at 2.0 years and 71% at 1.5 years (Fig. 3). On severely infected stands, those stands with needle retentions near 1.0, diameter growth is reduced to nearly 50% of maximum potential growth.

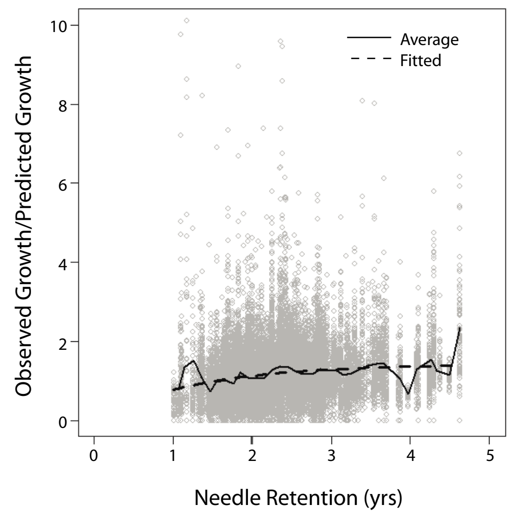


Figure 1. Scatterplot of observed growth / predicted growth (DMOD, grey circles), average line based on the average DMOD within each 0.1 needle retention class (solid line), and fitted line based on Eq. [1].

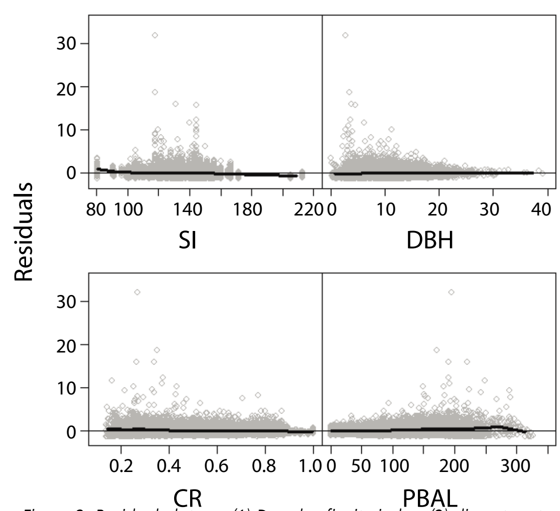


Figure 2. Residual plots on (1) Douglas-fir site index, (2) diameter at breast height, (3) crown ratio, and (4) basal area in larger (grey circles) from Eq. [1]. The average trend in the residuals is represented by the solid black line.

Table 1. Stand and tree characteristics by study

Variable	Growth impact		Precommercial thinning		Commerical thinning		Retrospective thinning study	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Plots	76		23		30		22	
Trees	3270		1683		3100		1060	
Observations	9287		4874		4394		1060	
Breast height age	14.3	5.7 - 30.0	12.8	7.6 - 17.5	35.8	19.8 - 60.4	43.6	33.1 - 62.5
Site index (ft)	135.1	80.4 - 212.9	142.3	105.3 - 207.7	135.8	115.3 - 159.7	125.1	96.3 - 143.6
FR (years)	2.3	1.1 - 3.1	2.5	1.1 - 3.4	2.4	1.3 - 4.6	2.8	2.0 - 4.4
BA (ft2ac-1)	112.8	7.5 - 284.9	108.2	19.0 - 315.0	220.4	145.6 - 331.0	143.2	82.1 - 207.7
DBH (in)	7.8	0.1 - 22.2	6.4	1.2 - 14.2	12.6	2.1 - 39.1	15.7	4.5 - 28.3
HT (ft)	45.8	4.6 - 113.6	39.6	12.1 - 68.8	90.4	23.3 - 175.1	101.1	26.7 - 157.2
CR	0.67	0.21 - 1.00	0.67	0.19 - 0.97	0.37	0.14 - 0.84	0.46	0.15 - 0.82
BAL (ft2ac-1)	63.4	0.0 - 254.8	65.8	0.0 - 300.9	133.4	0.0 - 326.0	86.4	0.0 - 207.5

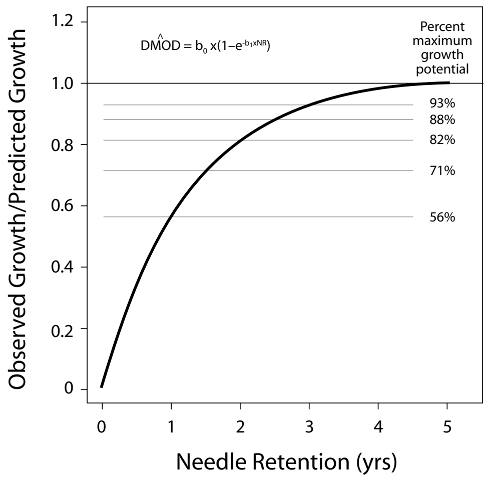


Figure 3. Fitted line based on Eq. [1] on needle retention. Horizontal lines represent (form top to bottom) an asymptote of 1.0 and the percent of maximum growth potential at needle retentions of 3.0, 2.5, 2.0, 1.5, and 1.0 years.

Equation [1] and by implication, SNC, accounted for very little variation in the diameter growth modifier. Residuals suggest small trends with SI, initial CR, and BAL. The trends in CR and BAL suggest that smaller trees within the stand grow faster than what ORGANON predicts. This finding is of minor consequence because these trees were generally of a size that contributed very little to total stand basal area and growth. This bias is most likely a consequence of the plots containing varying amounts of natural regeneration.

The overall magnitude and range of the diameter growth modifier, however, is a little more disconcerting. It must be kept in mind that the equations used in the SMC variation of the ORGANON used in this analysis were parameterized with very few permanent growth plots in the Oregon Coast Range. On the other hand, an independent assessment of the diameter and height growth equations used in this variant of ORGANON showed relatively little prediction bias in healthy (NR>3) stands. The more likely factor is the highly dynamic nature of SNC disease biology and infection biology, which is well correlated with oscillations in annual climate. These fluctuations can make it difficult for a model such as ORGANON with a 5-yr time step to make accurate predictions.

Overall, the diameter growth modifier developed in this analysis provides a quick and relatively easy fix to a difficult problem. Given the difficulty in defining a good relationship between the diameter growth modifier and SNC, developing annualized growth equation from the SNCC data may prove to be a viable alternative solution.

Literature Cited

Bruce, D. 1981. Consistent height-growth and growth rate estimates for remeasured plots. Forest Science 27: 711-725.

Hann, DW, DD Marshall, and ML Hanus. 2003. Equations for predicting height-to-crown-base, 5-year diameter-growth rate, 5-year diameter-growth rate, 5-year diameter-growth rate and maximum size-density trajectory for Douglas-fir and western hemlock in the coastal region of the Pacific Northwest. Forest Research Laboratory, Oregon State University, Corvallis. Research Contribution 40. 83 p.

Kanaskie, A, DA Maguire, and DB Mainwaring. 2002. Influence of pre-commercial thinning on Swiss needle cast severity and tree growth in north coastal Oregon. Pp. 25-27 in G. Filip (ed). Annual Report 2002, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, OR.

Maguire, DA, A Kanaskie, R Johnson, G Johnson, and W Voelker. 1998. Swiss Needle Cast Growth Impact Study: Report on results from Phases I and II. Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, OR. Internal report. 26 p. + App.

Maguire, DA, A Kanaskie, W Voelker, R Johnson, and G Johnson. 2002a. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. West. J. Appl. For. 17:86-95.

Maguire, DA, A Kanaskie, DB Mainwaring, R Johnson, and G Johnson. 2002b. Growth Impact Study: Growth trends during the second 2-yr period following establishment of permanent plots. Pp. 28-32 in G. Filip (ed). Annual Report 2002, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, OR.

Mainwaring, DB, DA Maguire, and A Kanaskie. 2004. Interactive effects of Swiss needle cast and commercial thinning on Douglas-fir growth and development in North coastal Oregon: Results from the first 15 permanent plots. Pp. 80-90 in D. Mainwaring (ed). Annual Report 2004, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, OR.List of figures

Interactive Effects of Swiss needle cast and commercial thinning on Douglas-fir growth and development in north coastal Oregon: 2006 remeasurement

Doug Mainwaring, OSU; Doug Maguire, OSU; Alan Kanaskie, ODF; Jeff Brandt, ODF

Introduction

In 2001, the Oregon Department of Forestry (ODF) undertook a two-phase study to examine the effects of commercial thinning in stands infected with Swiss needle cast (SNC). Prior to implementing this study, thinning had been avoided as a tool to improve crown vigor because field observations and limited data suggested that thinning stands with severe Swiss needle cast might accelerate symptom development and associated growth declines. However, for ODF, thinning is a necessary silvicultural tool for meeting the objectives of its structure-based management plan (Oregon Dept. of Forestry 2001). Furthermore, with large holdings of merchantable Douglas-fir in the SNC zone, this agency is especially concerned with the effects of thinning where SNC is a problem.

The study proceeded in two phases: 1) Retrospective—45 plots were established over two years in stands thinned 4-10 years previously to monitor the growth response to thinning; 2) Permanent—30 control/treatment paired plots were established over two years in stands just prior to thinning to monitor the response of growth and disease development. Results from the retrospective phase indicated that volume and basal area growth depended on disease intensity (as measured by both foliage retention and crown sparseness), and that average volume growth losses in the most heavily infected stands represented by the dataset were ~36%. Nevertheless, on average, stands had responded positively to thinning, with greater thinning intensities resulting in increased response (Mainwaring et al. 2005).

Among the unanswered questions of the retrospective phase was the effect of thinning on foliage retention. In the two overlapping growth periods over which the two sets of permanent plots have been monitored, foliage retention in heavily infected plots decreased during the first period, and increased during the second period, suggesting that annual variations in the factors that influence SNC infection levels are probably as influential or more so than thinning itself. As with the retrospective phase, cubic volume growth depended on foliage retention, crown sparseness, and other covariates, with growth losses on the most heavily impacted plots averaging ~32%. The difference in average maximum volume growth loss between the retrospective (36%) and permanent (32%) phase results from the different foliage retention and crown sparseness values used to define a “healthy” and a heavily infected stand; when using comparable values to represent healthy and infected stands, calculated growth losses were essentially equivalent. Contrary to the retrospective phase, which covered a longer time period, the permanent plots did not show a significant growth response to thinning after two years. However, analysis of the growth of individual trees on the permanent plots showed that large trees in infected stands were growing at a significantly higher percentage of their expected "healthy" growth than were small trees. While this is not unexpected given that the largest, and thus fastest growing trees in a stand are demonstrating a greater degree of disease tolerance when grown in the presence of SNC, coupled with the retrospective results it implies that thinning from below or leaving large Douglas-fir in a green tree retention harvest may be done without concern for a negative response.

This report addresses the four-year remeasurement of retrospective and permanent plots established in the fall of 2001. The objective of this remeasurement, undertaken over the winter of 2005-06, was to monitor current SNC conditions in state forests, and to further assess the growth and disease response of both types of plots to thinning.

Methods

The study sites were distributed across six different northwestern Oregon ODF districts (Tillamook, Forest Grove, Astoria, West Oregon, Santiam, Coos), five of which include land in the Coast Range. The Santiam district is located entirely within the Cascades, and was included due to evidence of low severity SNC in this province (Freeman 2002). Plots were distributed from 43.50° to 46.16° N latitude, from 124.06° to 122.5° W longitude, and from 30 to 800 m above sea level (Figure 1a,b). Over the last 40 years in this region, the mean January minimum was 0°C and the mean July maximum was 25°C. Total annual precipitation averaged 150-300 cm, with approximately 70% of the total falling from October to March.

Retrospective plots

Target stands were 30 to 60 years of age, contained at least 75% by basal area of Douglas-fir, and had undergone commercial thinning 4 to 10 years ago. Plot locations were distributed across a range of disease severity classes and residual densities, and included different aspects and slopes. Forty-five fixed area plots were established during the winters of 2001 (24 plots) and 2002 (21 plots) (Table 1). In a representative part of each stand, a square, 0.2 hectare plot (0.5 acre), was established. These plots were measured during the dormant season and annual basal area growth was reconstructed for varying periods before and after the last thinning. Four-year remeasurement of 23 of the plots established during 2001 included measurement of diameter, height and height to lowest live branch on previously subsampled trees, and foliage retention.

A

B

*Figure 1 Retrospective plot locations in CT thinning study (**A**). Paired plot locations in CT thinning study (**B**).*

Permanent plots

Fifteen pairs of fixed area plots were established during each of the winters of 2001 (2002-03 period) and 2002 (2003-04 period) (Table 2). These plots were measured during the dormant season. Plot locations were distributed across a range of disease severity classes and initial densities, and included different topographical aspects and slopes. Target stands were 30 to 60 years of age, had at least 75% of the basal area in Douglas-fir, and were scheduled for thinning prior to the growing season. Plot locations were chosen from candidate timber sales, or areas where a lack of planned activities made them available for experimental thinning on the treated plot. Initial SDI on thinned plots averaged 345 (range: 246-451), and average residual SDI was 190 (95-286). Thinning intensity ranged from 16-68% (by SDI) of initial SDI.

In a representative part of each stand, two square, 0.2 ha (0.5 ac) plots were established, each with its own 21-m buffer, for a total of a 0.8 ha (2-acre) treatment area (Figure 2). Where possible, the treatment plot was contiguous to the control plot. Measurements were confined to the inner 0.2-ha square. Prior to thinning, all trees >5 cm on the treatment plot were marked at breast-height with paint and measured for DBH (nearest 0.1 cm). When thinning had been completed, all trees > 5 cm on both plots were tagged and measured for dbh, with the tags on the treatment plot placed on the paint mark. Four-year remea-

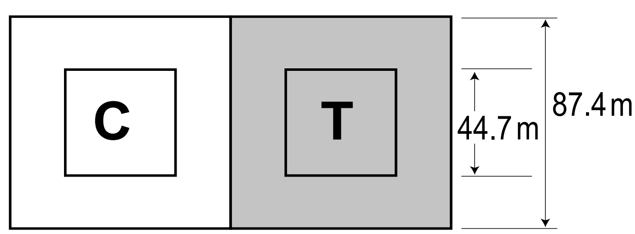


Figure 2 Dimensions of paired plots

Table 1: Attributes of the retrospective plots

Plot	Type	ODF dist.	Vol PAI (m^3/ha, 2002-05)	Site index (m/50y)	RD (at thin) ($ft^2/ac/in^{0.5}$) (Curtis 1982)	Foliage retention (y, 2002)	Foliage retention (y, 2006)	CL:SA (cm/cm^2)	Douglas-fir basal area (m^2/ha)	Years since thinning	Age (yrs)
Bcamp	ret	FG	18.83	30.3	28.3	3.48	4.38	7.23	31.5	9	49.3
BRidge	ret	Coos	21.57	36.7	30.5	2.38	3.05	6.22	30.1	5	45.4
BS20	ret	Till	12.73	39.8	17.4	2.86	3.25	7.2	18.9	6	39.8
BS35	ret	Till	12.00	42.6	36.8	3.13	3.58	12.39	34.4	6	41.7
Cope20	ret	Till	14.22	40.5	19.1	3.52	3.82	5.72	19.7	7	34
Cope35	ret	Till	12.52	42.8	28.2	2.38	2.85	10.95	26.9	6	37.7
Cbf	ret	WO	26.53	43.8	31.1	3.13	3.33	10.78	31.3	5	35.1
Cbs	ret	WO	20.92	37.7	33.2	2.85	3.00	9.87	32.0	5	34.6
Cedar	ret	Till	14.17	41.5	29.1	2.1	2.38	9.54	26.4	5	37.6
Cochran	ret	FG	23.84	41.8	41.6	3.6	4.48	5.97	45.1	6	54.5
Cole	ret	Ast	6.56	32.8	45.3	2.11	2.80	13.55	47.5	4	62.5
Fox	ret	Till	13.80	38.0	33.7	2.75	2.95	7.51	36.1	6	45.1
Gbasin	ret	Sant	16.98	32.0	33.4	3.1	4.34	10.97	29.5	4	40.1
KFalls	ret	Till	11.41	40.2	25.9	2.34	2.36	8.99	25.3	5	35
KiLo	ret	Till	15.35	40.2	36.4	2	2.50	11.27	36.4	7	34.2
Moot	ret	Till	8.66	35.3	28.7	2.19	2.22	11.12	27.0	5	54.5
Mrph	ret	Till	14.40	38.5	31.7	2.78	3.05	6.64	34.3	7	39.8
Sleep	ret	FG	24.83	42.9	34.9	4.38	4.78	6.37	40.0	8	52.5
Smill	ret	Sant	22.89	31.8	48.4	2.55	3.94	11.97	47.6	6	56.3
Stburn	ret	FG	12.72	29.4	31.7	3.65	4.95	6.18	26.5	5	42.3
Stmpot	ret	Till	13.19	41.8	29.6	2.6	2.70	7.44	30.2	8	53.8
TB	ret	Coos	15.58	38.6	33.2	2	2.18	7.02	30.6	4	33.1
Wport	ret	Ast	9.78	36.2	45.3	1.8	1.93	11.4	37.2	4	36.8
Max			26.5	43.8	48.4	4.38	4.95	18.05	47.6	9	69.3
Min			6.56	29.4	17.4	1.8	1.93	5.97	18.9	4	33.1
Mean			15.80	38.1	31.0	70	3.25	8.9	32.4	5.78	42.3

Table 2: Attributes of the permanent plots

Plot	Trt	ODF dist.	Vol PAI (m^3/ha, 2002-03)	Vol PAI (m^3/ha, 2004-05)	Site index (m/50y)	RD (at thin) (ft^2/ac/in0.5) (Curtis 1982)	Foliage retention (y, 2002)	Foliage retention (y, 2006)	CL:SA (cm/cm^2)	Douglas-fir basal area (m^2/ha)	Non-DF BA (m^2/ha)	Age (yrs)
Brownsmd	cont	Ast	16.58	19.35	46.1	64.7	2.00	2.55	5.8	38.8	14.0	32.2
Brownsmd	thin	Ast	13.70	17.62	46.1	32.7	2.08	2.75	5	28.1	0.9	31.7
Clammer	cont	Till	14.26	15.10	44.6	65.1	1.95	1.90	4.9	37.1	15.1	29
Clammer	thin	Till	6.86	11.63	42.6	27.8	1.85	2.05	5.5	19.5	3.4	34
Cook wright	cont	Till	13.70	17.88	40.9	63.6	1.75	1.75	8.3	36.2	11.7	29.2
Cook wright	thin	Till	4.99	9.21	39.1	24.8	2.21	2.38	7	13.7	5.7	28.3
Fall Hatch	cont	WO	16.86	19.25	40.2	68.5	2.00	2.20	5.5	67.1	1.6	60.1
Fall Hatch	thin	WO	7.49	9.02	40.5	22.4	2.00	2.50	7	25.4	0	60.4
Gales Creek	cont	FG	18.33	23.26	23.3	53.2	3.88	4.50	4.4	48.0	2.9	47.5
Gales Creek	thin	FG	10.83	16.33	16.3	29.2	3.70	4.25	5.4	31.3	0	48
Gold Peak	cont	Till	17.79	24.96	42.6	46.1	2.00	2.15	4.7	41.1	0	32.8
Gold Peak	thin	Till	11.92	23.03	40.9	43.4	2.00	2.28	5	37.4	0	31
Hagg Lake	cont	FG	23.7	26.58	40.8	64.9	4.25	4.75	5.2	55.6	0	44
Hagg Lake	thin	FG	14.09	18.34	39.5	31.6	4.30	4.80	3.7	30.4	0	42.2
Kilchis	cont	Till	13.90	21.51	37.7	63.7	1.56	1.39	7.2	47.2	0	32.7
Kilchis	thin	Till	7.46	16.34	39.9	39.1	1.46	1.38	6.5	29.5	0	30
Lower Wolf	cont	WO	20.39	21.59	47.4	72.6	3.30	3.35	4.8	70.5	4.2	54.3
Lower Wolf	thin	WO	10.81	10.53	46.3	29.8	2.65	2.96	5.5	39.2	0	55.6
Miami Stu	cont	Till	12.61	19.91	37.8	44.9	1.33	1.23	4.3	36.6	4.0	33.8
Miami Stu	thin	Till	5.67	7.63	37.6	25.6	1.45	1.39	5.1	19.4	4.7	32.6
Sam Downs	cont	Till	9.62	14.12	38.2	57.3	1.46	1.18	5.4	38.6	3.7	31.3
Sam Downs	thin	Till	6.55	10.29	40.5	38.3	1.30	1.17	6.5	25.3	4.5	32.1
Soapstone	cont	Ast	13.68	21.40	43.3	64	1.90	1.80	7.5	44.4	8.6	34.8
Soapstone	thin	Ast	11.43	19.51	44.7	42.8	1.75	1.61	8.5	36.1	0.1	33
Toll Road	cont	Till	16.49	20.62	41.4	47	1.85	2.00	4.4	37.7	1.6	28.3
Toll Road	thin	Till	7.51	11.48	42.3	26.3	1.45	2.00	4.5	19.6	2.6	29.4
Tom rock	cont	Sant	12.27	17.63	36.5	71.4	3.20	4.50	9.7	54.3	4.7	59.4
Tom rock	thin	Sant	9.96	13.94	40.2	37.9	3.20	4.25	10.1	31.6	2.9	59.8
Westport	cont	Ast	21.98	26.31	43.7	54.2	3.55	4.05	5.4	40.8	5.2	27.8
Westport	thin	Ast	18.55	21.86	41.6	33.6	3.45	3.95	4.6	30.3	0.1	26.4
Mean			16.18	17.54	41.4	46.5	2.4	2.4	6.0	36.9	2.4	35.8
Max			30.89	26.58	48.7	77.5	4.6	4.6	10.1	70.5	15.1	60.4
Min			4.99	7.63	35.1	16.4	1.3	1.3	3.7	12.9	0	19.8

surement of 15 of the plots established during 2001 included measurement of diameter, height and height to lowest live branch on previously subsampled trees, and foliage retention.

Analysis

For the retrospective data, regression equations were used to assess 1) change in foliage retention since 2002; 2) periodic annual volume increment; and 3) basal area growth ratio based on different 4-year growth periods before and after thinning. Equations included numerous covariates to account for differences in Douglas-fir basal area, basal area of other species, site index, relative density, quadratic mean diameter, crown ratio, crown length, and age between plots. Variables were included in the final model only if they were significant at α=0.05. When comparing post-thinning and pre-thinning basal area growth, the ratio was based on the residual trees only, since growth of the cut trees prior to thinning was unknown.

To test whether thinning affected foliage retention on permanent plots, the data were analyzed as a randomized block experiment, adjusted for covariates. Each pair of plots was a block with one control and one thinned plot. Numerous covariates were combined with these categorical variables, including initial foliage retention, initial crown sparseness (live crown length (cm)/sapwood area at crown base (cm^2); (Maguire and Kanaskie, 2002), site index, and variables representing initial density and thinning intensity. Variables were included in the final model only if they were significant at α=0.05. To isolate the "effect" of initial SNC severity on growth response to thinning, both stand and individual tree periodic annual volume growth (volumes estimated with Bruce and Demars 1974) was regressed on foliage retention and crown sparseness, in addition to other covariates that typically influence stand growth. The latter variables included Douglas-fir basal area, basal area of other species, site index, relative density, quadratic mean diameter, crown ratio, crown length, age, removed basal area, indicator variables for treatment and growth period, and various interactions. Variables were again included in the final model only if they were significant at α=0.05.

Results

Retrospective plots

2006 Foliage retention

Foliage retention on all plots increased between 2002 and 2006 (Figure 3).

Approximately 92% of the variation in the 2006 foliage retention was explained by the following model (MSE of 0.074):

[1] $FOLRET06 = b_0 + b_1 \ln(FOLRET02) + b_2(BA_{df}) + b_3 \ln(SI)$

where FOLRET06 = Foliage retention, 2006 (yrs)
FOLRET02 = Foliage retention, 2002 (yrs)
BA_{df} = Douglas-fir basal area (m^2/ha)
SI = Site index (DF, 50 years, m)

Parameter estimates (Table 3) indicated that 2006 stand-level foliage retention was positively correlated with 2002 foliage retention and Douglas-fir basal area and negatively correlated with site index.

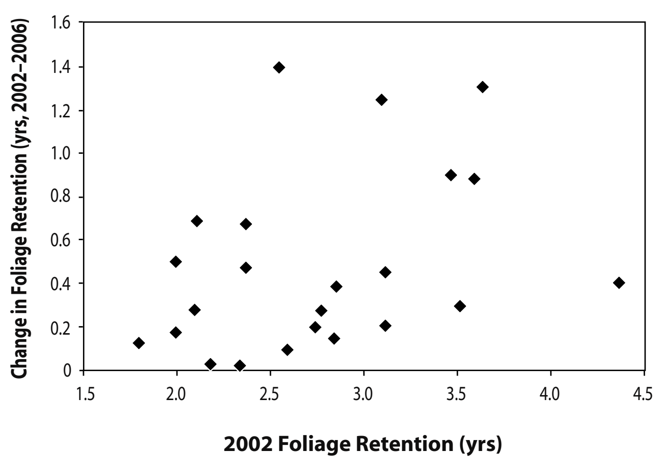


Figure 3 Change in foliage retention on retrospective plots as of 2006, relative to initial 2002 foliage retention.

Table 3. Parameter estimates for model describing the change in foliage retention (equation [1]).

Variable	Parameter estimate	Standard error
a_0	6.79377	1.87857
a_1	3.44075	0.25108
a_2	0.01593	0.00771
a_3	-2.05676	0.49582

Periodic annual volume increment

Periodic annual volume growth since 2002 was also related significantly to SNC indices, as well as other covariates representing stand density and tree age. Approximately 57% of the variation in the logarithm of periodic annual volume increment was explained by the following model (MSE of 0.069):

$$[2] \quad \ln(VPAI) = b_0 + b_1\ln(BA_{df}) + b_2\ln(FOLRET02) + b_3(CLSA) + b_4(AGE)$$

where VPAI = Periodic annual volume increment of plot since thinning (m^3/ha/yr)

CL:SA = Crown sparseness (cm/cm^2)

AGE = Breast-height age (yrs)

And BA_{df} and FOLRET02 are defined above.

Table 4. Parameter estimates for model describing periodic annual volume increment (equation[2]).

Variable	Parameter estimate	Standard error
b_0	2.93189	1.10108
b_1	0.82986	0.28093
b_2	0.72786	0.29938
b_3	-0.05517	0.02922
b_4	-0.89132	0.34823

Parameter estimates (Table 4) indicated that stand-level periodic annual volume increment increased with increasing Douglas-fir basal area and foliage retention, and decreased with increasing crown sparseness, and age.

Volume growth varies dramatically across the range in foliage retention and CL:SA (Figure 4). Expected volume growth losses experienced by stands having lower levels of foliage retention and higher levels of crown sparseness than a "healthy" stand (Forest Grove and Santiam district averages) range up to ~59% (Figure 5).

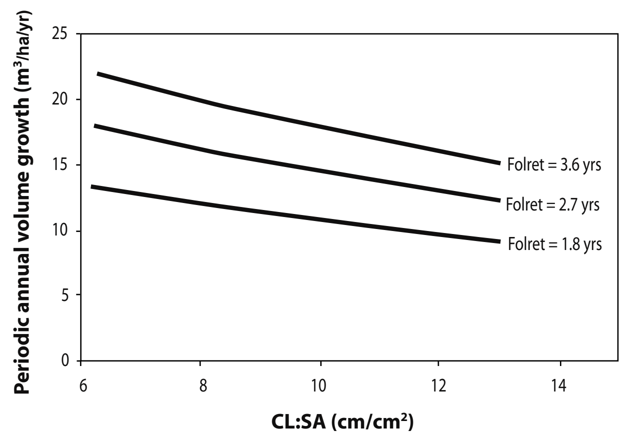


Figure 4 Periodic annual volume growth implied by equation [2] assuming mean Douglas-fir basal area (32.3 m^2/ha) and age (42.3 years)

Basal area growth ratio

Stand-level basal area growth in the 2002-05 period was greater than in the 4-year period just prior to thinning and in the 4-year period just after thinning on all plots. The ratio of period 2 basal area growth to period 1 basal area growth (BAR21) (Figure 6) indicates that basal area growth of residuals was lower in the period immediately after thinning than it was in the period just prior to thinning in about half of the stands (Figure 7). Nevertheless, a t-test showed no difference in foliage retention of stands where growth in the first period after thinning increased or decreased.

In period 4, the 4-year period from 2002-05 (Figure 6), BA growth of all stands but one improved in absolute terms relative to the period prior to thinning, with BAR41 (ratio of period 4 to period 1 growth) varying from 1.47 to 5.01 (Figure 7) in stands where growth increased. This ratio was significantly related to SNC intensity, stand density, crown ratio, and time since thinning. Approximately 72% of the variation in the ratio of period 4 to period 1 growth was explained by the following model (MSE = 0.384):

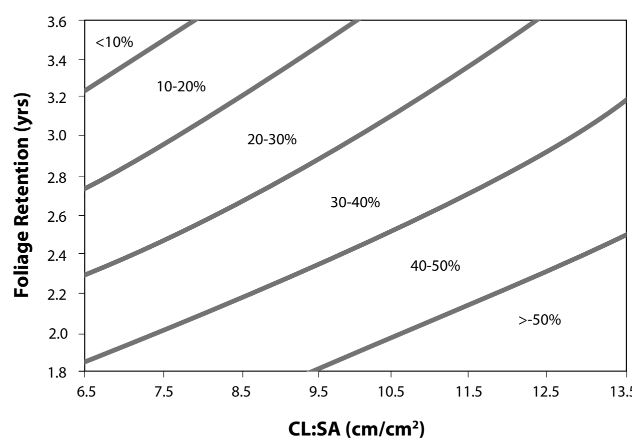


Figure 5 Implied growth loss implied by equation [2], assuming mean Douglas-fir basal area (32.3 m^2/ha) and age (42.3 years)

$$[3] \quad BAR41 = c_0 + c_1\ln(BA_{df}) + c_2\ln(CL{:}SA) + c_3\ln(YST) + c_4CR$$

where BAR41 = Ratio of BAG (period4/period1)

YST = Years since thinning

CR = Crown ratio (expressed as a decimal)

and BA_{df} and CL:SA are defined above.

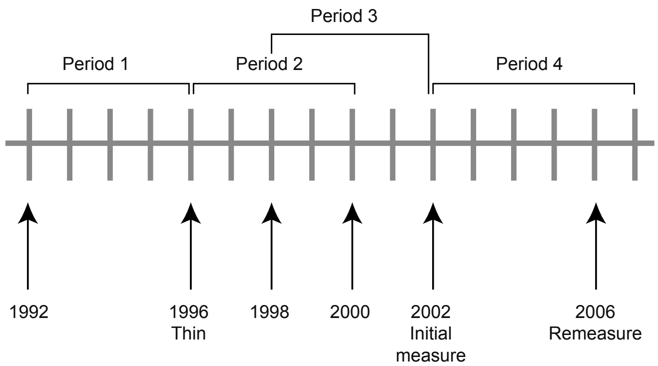


Figure 6 Periods corresponding to basal area growth ratio for a stand thinned 6 years prior to the 2002 measurement. Period 1=4 years immediately prior to thinning; Period 2=4 years immediately after thinning; Period 3=4 years immediately prior to 2002 measurement; Period 4=2002-05 growing seasons

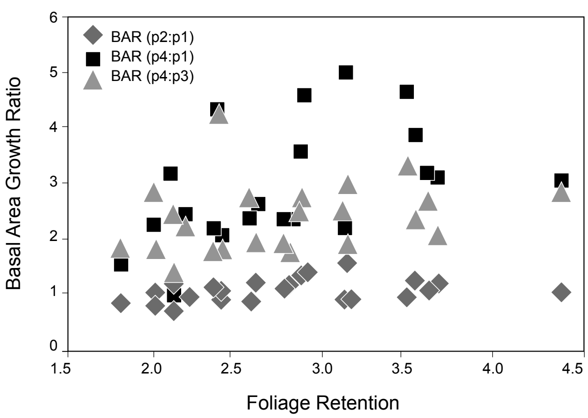


Figure 7 Basal area growth ratio for different periods. Periods defined in figure 6.

Table 5. Parameter estimates for model describing basal area ratio of period 4 and period 1 (equation [3]).

Variable	Parameter estimate	Standard error
c0	23.19702	6.30199
c1	-1.99962	0.75514
c2	-3.62619	1.17143
c3	1.52119	0.81645
c4	-15.51072	5.83599

The ratio (response to thinning) increased with years since thinning and decreased with increasing basal area, crown sparseness, and crown ratio (Table 5). Represented graphically, the implied response varies significantly across different levels of residual density and SNC infection (Figure 8). Regression results also imply that the ratio may be less than one at high levels of SNC and stand density. This result was driven by one plot, where a combination of age (67 years in 2006) and relatively low site index (32.8 m), limited tree response to thinning.

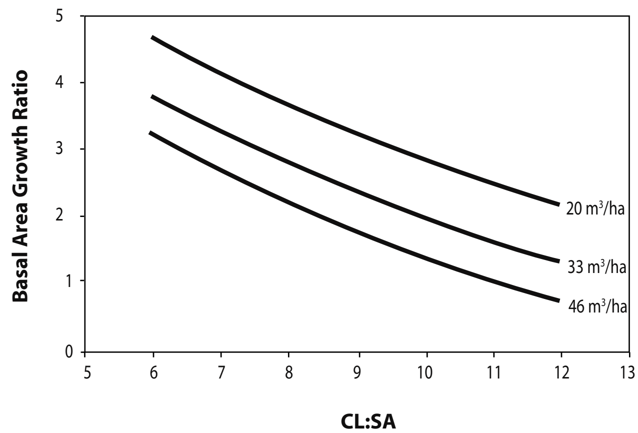


Figure 8 Model implied basal area growth ratio (period 4: period 1) at varying levels of crown sparseness and different initial basal areas, assuming mean levels of years since thinning (5.78 yrs) and crown ratio (0.54).

Permanent plots

Change in Foliage retention

While changes in plot-level foliage retention were both positive and negative for the first group of 15 permanent plots during the first growth period, in the second growth period they were generally positive. In fact, many of the plots that experienced foliar losses after the initial treatment showed a general pattern of recovery in the second period (Figure 9). Complicating simple explanations is geographic variation among coastal plots: Trask River area plots (Toll Road and Gold Peak) improved more than more northerly Tillamook and Astoria district plots (Miami Stu, Sam Downs, Kilchis Lookout, Soapstone) (Figure 9).

When analyzing the first two growth periods separately as a randomized block experiment, thinning did not significantly affect the change in foliage retention, with or without additional covariates in the model. However, when analyzed for the entire four-year period, thinning had a significant positive effect (p=0.032), with an average increase of 0.1 years of foliage (Figure 10). Because there was significant between-block variation due to factors such as site index, stand density, and SNC infection levels, regression analysis by replacement of block effects with variables describing these differences was attempted, though correlations were either uninteresting or explained a low amount of variability.

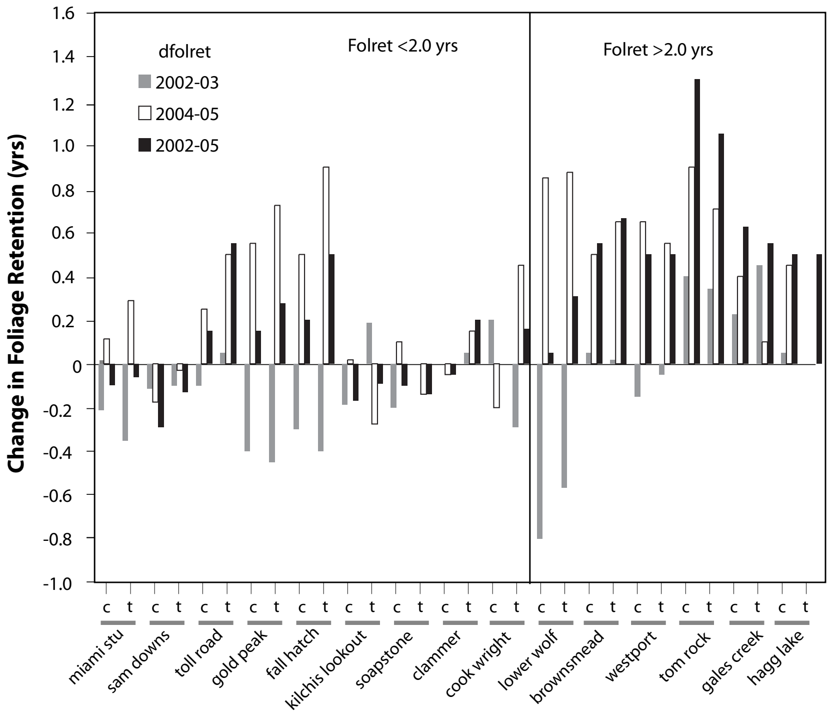


Figure 9 Change in foliage retention on control and treatment plots: period 1 (2002-03), period 2 (2004-05), and combined (2002-05).

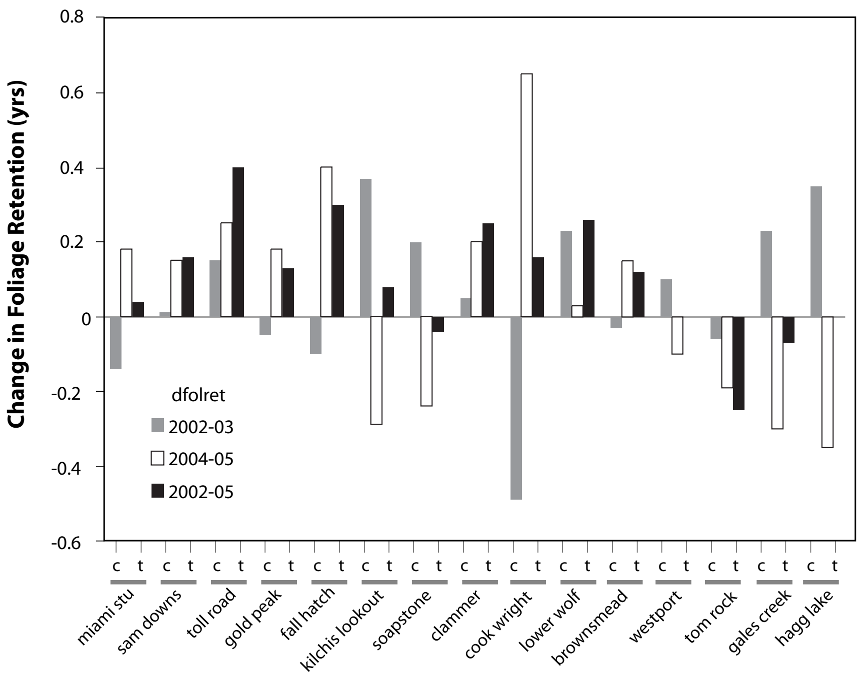


Figure 10 Net change in foliage retention with treatment (adjusted for control plot change): period 1 (2002-03), period 2 (2004-05), and combined (2002-05).

Periodic annual volume increment

Treated as a randomized block experiment, both block and treatment effects were significant in explaining volume increment. However, when initial Douglas-fir basal area was included as a covariate, treatment effect was no longer significant. Plot attributes varied considerably (Table 2), underscoring the need to account for covariates other than those representing SNC severity. Volume growth since thinning was significantly related to initial SNC levels and other covariates reflecting stand density and age.

Approximately 85% of the variation in the logarithm of periodic annual volume increment was explained by the following model (MSE = 0.019):

[4] $\ln(VPAI) = d_0 + d_1\ln(BA_{df}) + d_2\ln(FOLRET04) + d_3\ln(AGE)$

where
FOLRET04 = Foliage retention for the plot, 2004 (yrs)

and VPAI, BA_{df} and AGE are defined above.

Table 6. Parameter estimates for model describing periodic annual volume increment (equation[4]).

Variable	Parameter estimate	Standard error
d_0	1.97255	0.46827
d_1	0.95208	0.11241
d_2	0.34750	0.07272
d_3	-0.76357	0.11088

Parameter estimates (Table 6) indicated that periodic annual volume increment increased with increasing Douglas-fir basal area and foliage retention, and decreased with increasing age. At an age of 35 years, implied cubic volume growth varied from 7 to nearly 35 m^3/ha/yr depending on Douglas-fir basal area and foliage retention (Figure 11). When compared to a healthy stand (represented by mean SNC index values from Gales Creek, Hagg Lake, Westport, and Tom Rock foliage retention: 4.0 years), growth losses in the most heavily infected stands (folret=1.1 yrs) are implied to be 31%.

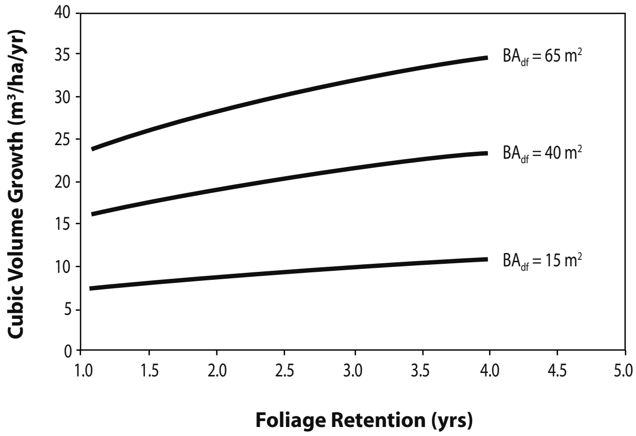


Figure 11 Cubic volume growth implied by equation [4] at varying levels of initial foliage retention, based on a stand age of 35 years

Individual tree growth

In order to determine how individual trees are responding to treatment, an individual tree model was constructed using the subset of trees which had been measured for height and height to lowest live branch on each plot. Approximately 82% of the variation in the logarithm of periodic annual volume increment was explained by the following model (MSE = 0.22):

[5] $\ln(VPAI) = c_0 + c_1\ln(DBH) + c_2(DBH)\ c_3\ln(CR) + c_4\ln(FOLRET04) + c_5(CUTBA)\ c_6\ln(BA_{total})$

where DBH = Diameter at breast height (in)
CUTBA = Removed basal area per acre (m^2)
BA_{total} = Residual basal area, all species (m^2/ha)

And VPAI, CR, and FOLRET04 are as defined above

Table 7. Parameter estimates for model describing periodic annual volume increment of individual trees (equation [5]).

Variable	Parameter estimate	Standard error
e0	-14.05429	0.50431
e1	4.89374	0.16248
e2	-0.06246	0.00450
e3	0.42394	0.06782
e4	0.18480	0.03921
e5	-0.01523	0.00292
E6	-0.83318	0.10505

Parameter estimates (Table 7) indicated that periodic annual volume increment increased with increasing diameter (for all but the largest trees in the dataset), crown ratio, and foliage retention, and decreased with increasing residual basal area, and removed basal area.

Although removing more basal area to achieve a given residual basal area had a negative effect on individual tree growth, this was more than compensated by the positive effect of lower stand density, as reflected in the BA_{total} variable. As a result, lowering stand density by thinning had a net positive effect on individual tree growth in the second period (Figure 12).

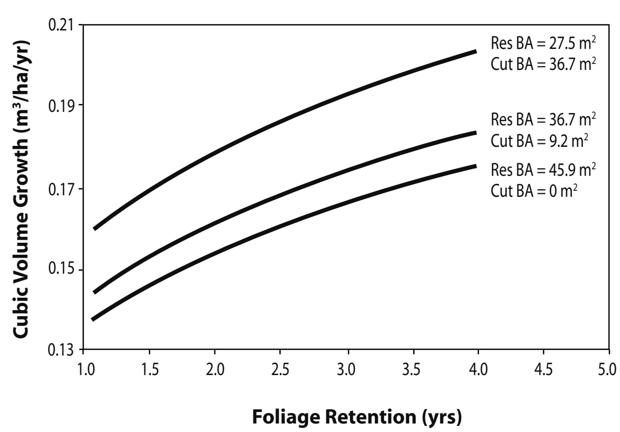


Figure 12 Individual tree volume growth implied by equation [5] at varying levels of initial foliage retention, assuming average dbh (38 cm) and crown ratio (50%)

Discussion

The most difficult stands for estimating foliage retention are those with high foliage retention and/or low shoot growth because both factors create a dense crown, making distinctions between annual complements difficult. These conditions characterized the retrospective stands that improved the most in regard to foliage retention, perhaps for several reasons. Most obviously, conditions may have improved in such a way that foliar retention has generally improved. However, foliage retention on the retrospective plots was first estimated in 2002 for this study, so it is likely that the accuracy of estimation has improved with four years of experience. This second scenario raises a question: if confidence in the 2002 estimates has diminished, do model-implied growth losses in 2006 accurately reflect the purported 2002 SNC levels? It appears they do because, across all plots, the 2006 foliage retention is proportionally similar to the 2002 retention, and substituting the 2006 foliage retention into equation [2] produces a nearly identical result.

Although the values of foliage retention and crown sparseness constituting healthy and infected stands used in 2002 were the same as those used in 2006, growth loss estimates implied by equation [2] are considerably greater (max=59%) during the last four years than were pre-2002 estimates (max~37%). Why the difference? One explanation may be the method of estimating volume growth in 2002. In the previous retrospective analysis, calculation of volume growth required that initial heights be estimated using current height and expected dominant height growth given the measured site index. As stated in the original retrospective report, because height growth has been shown to diminish with SNC infection (Maguire et al. 2000), height growth estimated by this method would be overestimated for trees growing in infected stands, with subsequent underestimation of growth loss. Figure 13 shows the ratio of measured volume growth in 2002-05 to estimated volume growth from the time of thinning through the 2001 growing season. This graph suggests that volume growth on infected plots decreased as time since thinning has increased, though values of BAR43 indicate otherwise. Clearly, pre-2002 volume growth was overestimated on infected plots.

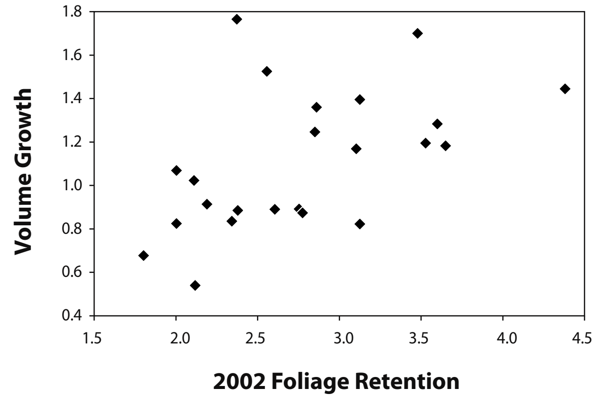


Figure 13 Ratio of 2002-05 PAI to pre-2002 post-thinning PAI on retrospective plots

A second factor is that because SNC-induced height and branch growth reductions (Mainwaring et al. 2002) can be expected to slow crown expansion, canopy closure and maximum individual tree growth response to thinning is delayed in infected stands. In this scenario, relative volume growth rate differences between healthy and infected stands would be maximized when previously thinned healthy stands have reached full site occupancy. Healthy stands would not only reach this stage more quickly in absence of SNC, but this difference is also exacerbated by the fact that plots with low foliage retention tended to have been thinned more recently (Table 2). This explanation is given more credence by the significance of the years-since-thinning variable in equation [3], even after accounting for differences in SNC level.

The basal area growth ratio of periods 4 and 1 (BAR41) (Figure 7) reinforce earlier findings that stands, on average, respond positively to thinning regardless of the level of SNC (Mainwaring et al. 2005). The much greater value of BAR41 vs. BAR21 also indicates that while only a few stands show a marked positive response in the first four years after thinning, a clear positive response occurs during the four year period starting 4-10 years later. This result was consistent with results from the permanent plots. Furthermore, basal area growth is continuing to accelerate in all stands, as evidenced by values of BAR43 greater than 1 (Figure 7). The longer average period of post-thinning growth acceleration experienced by the healthy stands probably led to the greater relative growth losses of the infected stands during the 2002-05 growth period.

Foliage retention, positively correlated with volume growth, was generally greater on the CT plots in the spring of 2006 than in either 2002 or 2004. The significant positive effect of thinning on permanent plot foliage retention shown in Figure 10, while small, was particularly evident on plots with low foliage retention. This phenomenon is probably the result of two factors: 1) foliage retention can be more precisely measured in infected trees due to better within-crown visibility—with a crown having more than 4 years of foliage, there is a tendency to give it a high, nominal value; and 2) Changes in SNC levels are more obvious in more heavily infected trees.

Interestingly, many trees in 2006 were observed to have a greater amount of three-year old foliage than two-year old foliage. Because only current year foliage can become infected during the period of shoot elongation (Stone et al. 2000), this suggests that conditions during 2004 were more conducive to fungal infection than were conditions in 2003. Why?

Previous work has shown that fungal germination rates are positively related to moisture levels during the period of shoot elongation, generally May-June (Manter et al. 2003). Figure 14 shows that precipitation measured at five weather stations throughout the study area (Nehalem, Otis Junction, Seaside, Tillamook, Willamina) in 2002 and 2003 was at its lowest level in the last 10 years. Tracking this was a decrease in acreage reported as showing SNC symptom expression by the ODF aerial survey in 2003 and 2004 (Kanaskie et al. 2005), suggesting a one-year delay in symptom expression. This delay is consistent with the spring moisture hypothesis, given that symptom expression takes place in older needle cohorts about to be cast, requiring at least one season of post-germination fungal development. In contrast, 2004 and 2005 precipitation at the same locations and during May and June was closer to normal, and ~88 and 164% higher respectively than in 2003 (Figure 14). Consistent with this pattern, the numbers of acres showing SNC symptoms as measured by the ODF aerial survey increased in 2005 (Kanaskie et al. 2005) and 2006 (Kanaskie, pers. comm.). It has been speculated that abundant moisture in the Coast Range, coupled with heavy spore loads during this period makes these precipitation totals unimportant. However, tracking the abovementioned trend in precipitation totals is the number of days per month without measurable precipitation during this period recorded at the same five weather stations. During May and June of 2003, there were, on average, 2 fewer days per month without precipitation than in 2004, and six fewer days without precipitation than in 2005 (Figure 15).

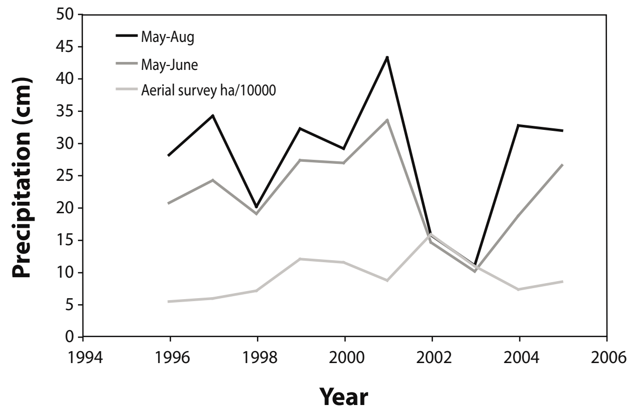


Figure 14 Measured precipitation by year; SNC impacted hectares/10000 as identified by ODF aerial survey

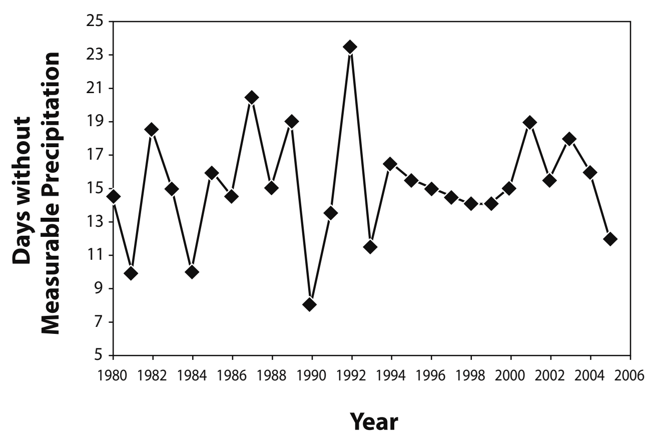


Figure 15 Number of days without measurable precipitation, May-June

What effect does this have on volume growth? Because the 2002 and 2003 needle cohorts were more lightly infected, more of those needles remain functional longer, thereby augmenting growth in the 2004-05 period. The volume growth on the 15 permanent plots during the second two-year period has represented an across-the-board increase relative to the first period, amounting to an average increase of ~30% on the control plots (range: 5-58%). While the change in foliage retention during the second period was not a significant covariate in the model describing volume growth, it is certainly an explanatory factor (as it was for all 30 permanent plots in the first period). The second likely explanation for increased volume growth is greater growing season precipitation (Figure 14). The favorable conditions during the 2004-05 period (relatively high retention, high growing season moisture) are in contrast to the 2002-03 period. The 2002-03 seasons followed a three-year period of high spring moisture, and maximum symptom expression (Figure 14), from which foliage retention could be inferred to be at minimum levels. When coupled with low levels of growing season precipitation (Figure 14), the 2002-03 growth period may represent a period of relatively low growth. The contrast in growing conditions between the two periods was thus great, and may, for the average stand, represent two extremes in growth performance.

When compared to a healthy stand (represented by mean foliage retention from Gales Creek, Hagg Lake, Westport, and Tom Rock: foliage retention: 4.0 years), growth losses in heavily infected stands (folret=1.1 yrs) are implied to be 31%. This value is comparable to that calculated for the first two-years of the full permanent plot dataset. However, when extreme values of foliage retention (healthy: 3.9 years and heavily infected: 1.3 years) from last year's two–year permanent plot report is used, the implied growth loss is only 27%, suggesting improved growth per unit of foliage retention. For reasons described in the preceding paragraphs, foliage in the 2002 and 2003 cohorts may be more lightly infected. While previous work has indicated that needles tend to be cast when ~50% of stomates are plugged (Hansen et al. 2000), retained foliage can presumably have between 0 and ~50% of stomates plugged. In this scenario, two trees can have similar foliage retentions, yet if one has retained needles with fewer plugged stomata, it would have improved volume growth per unit of foliage retention and greater photosynthetic capacity.

While a consistent positive growth response to thinning was not evident after the first two-year period, individual trees responded positively during the second two-year period. This response increased as the percentage of basal area removed increased (Figure 16). Also, because thinning stands usually leads to branch loss and shorter crowns for the residual trees, predicting the average response must take crown loss into account.

Why do individual trees show a significant thinning response but stands don't? First, the larger number of observations gained from using individual trees (>1000) versus plots (30) improves precision and reduces error. Secondly, important covariates such as crown ratio are almost meaningless on the plot level, where they are expressed as an average crown ratio of all trees sub-sampled for height. However, on the individual tree level, the importance of differences in crown ratio are indicated by the response curve shown in Figure 16: trees that have a 10% lesser crown ratio (i.e. 50%–40%) as a result of branch loss during removal of 31% of the stand's basal area are, on average, growing equivalently to trees in unthinned stands, after adjusting for differences in basal area. On the stand level, this result would be an insignificant thinning response. However, on the individual tree level, the response is significant, because the result accounts for differences in crown ratio. Although the positive response to thinning was not apparent on the stand level on the permanent plots, the increases in basal area growth ratio as time since thinning has increased on the retrospective plots (Figure 7) suggest that a stand-level growth response per unit basal area is likely to be apparent in the future.

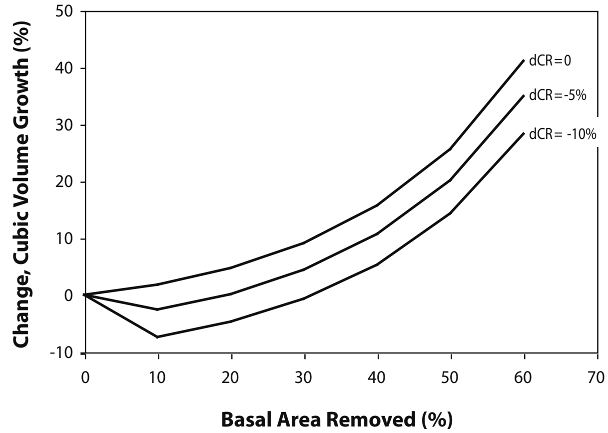


Figure 16 Implied percent change in individual tree cubic volume growth with thinning versus control, based on % basal area removed and crown ratio loss based on equation [5]

The increases in spring moisture in the last two years raises the question of what should be expected in subsequent years. It's likely that increases in spring moisture in the last two years will increase infection rates and may lead to relatively early needle losses in subsequent years. At the same time, the ability of stands to continue satisfactory growth may depend on continued retention of older, less infected needle cohorts from 2002 and 2003. While foliage has been found to lose production efficiency with aging (Teskey et al. 1984), this is partially the result of an increasingly shaded position within the crown and subsequent nutrient translocation to younger needle cohorts (Field 1983). However, in thin crowns, or where needle cohorts of intermediate age are missing, older needles may continue to be productive due to greater light availability. In addition, although spring moisture in 2005 was relatively high, it did not exceed that measured during three consecutive years between 1999-2001. That three-year period preceded the highest acreage of discoloration detected by the aerial survey, 387,000 acres in 2002. In other words, the high acreage value in 2002 came after three years of precipitation similar to that measured in 2005. Furthermore, Douglas-fir acreage within the SNC zone has been reduced significantly in that period, presumably reducing overall spore loads. In short, while infection levels will probably be greater on 2005 foliage than in either 2002 or 2003 foliage, it is unlikely that region-wide infection levels will approach that seen in previous years.

Literature Cited

Bruce, D. and Demars. 1974. Consistent height-growth and growth-rate estimates for remeasured plots. For Sci. 27:711-725.

Field, C. 1983. Allocating leaf nitrogen for the maximization of carbon gain: leaf age as a control on the allocation program. Oecologia. 56:341-347.

Freeman, F. 2002. Swiss needle cast monitoring in the Oregon Cascades. Pp. 11-14 in 2002 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Hansen, E.M., Stone, J.K., Capitano, B.R., Rosso, P., Sutton, W., Winton, L., Kanaskie, A., and M. McWilliams.

2000. Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in coastal Oregon. Plant. Dis. 84:773-778.

Kanaskie, A., McWilliams, M., Sprengel, K., and D. Overhulser. 2005. Pp. 9-11 in 2005 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Maguire, D.A., and A. Kanaskie. 2002. The ratio of live crown length to sapwood area as a measure of crown sparseness. For. Sci. 48:93-100.

Maguire et al. 2002. The reference this pertains to in the bibliography is the Maguire, Kanaskie, A., Voelker, W., Johnson, R., and G. Johnson. 2002.

Maguire, D.A., Kanaskie, A., Voelker, W., Johnson, R., and G. Johnson. 2002b. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. West J. Appl. For. 17: 86-95.

Mainwaring, D., Kanaskie, A., and D. Maguire. 2002. Pp. 82-86 in 2002 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Mainwaring, D., Maguire D.A., Kanaskie, A., and J. Brandt. 2005. Growth responses to commercial thinning in Douglas-fir stands with varying severity of Swiss needle cast in Oregon, USA. Can. J. For. Res. 35: 2394–2402.

Manter, D. Reeser, P., and J. Stone. 2003. Pp. 47-57 in 2003 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Oregon Dept. of Forestry. 2001. Northwestern Oregon State Forests Management Plan: Final Plan. Jan 2001. Oregon Department of Forestry, Salem, Oregon.

Stone, J., Winton, L., Reeser, P. Manter, D., Sutton, W., and E. Hansen. 2000. Pp. 13-19 in 2000 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Teskey, R.O., Grier, C.C., and Hinckley, T.M. 1984. Change in Photosynthesis and water relations with age and season in *Abies amabalis*. Can. J. For. Res. 14:77-84.

Growth Responses to Sulfur Application in Douglas-fir Stands With Swiss Needle Cast, 2006

*Doug Mainwaring, OSU; Doug Maguire, OSU; Jeff Stone, OSU;
Alan Kanaskie, ODF; Mark Gourley, Starker Forests; Charley Moyer,
Green Diamond*

Introduction

Because sulfur has shown potential for controlling Swiss needle cast infection (Stone et al. 2001), an experiment was initiated in spring of 2002 to test the effect of aerial application of sulfur on Swiss needle cast symptoms, the abundance of the causal fungus, and the growth of Douglas-fir (Stone et al. 2003). Two growing seasons after the initial application, growth analysis determined that treatment did not affect either basal area or height growth (Maguire et al. 2004). The objective of this report is to present the results for tree growth during the second two-year period following sulfur application (2004-2005).

Methods

Five-acre experimental units were chosen in pairs, with one unit serving as control and the other treated by aerial application of micronized sulfur (Stone et al. 2004). Within each experimental unit, a 0.5-ac measure plot was established. All trees were tagged and measured for dbh (nearest 0.1 cm) before the growing season in 2002, and a subsample of at least 40 Douglas-fir trees was measured for total height and height to crown base (nearest 0.1m). The experimental units were treated aerially with micronized sulfur, twice during June in each of the 2002 and 2003 growing seasons. The plots were remeasured in the spring of 2004, after two growing seasons, and again in the spring of 2006, after four growing seasons. Five plot pairs established in the Coast Range of Oregon were available for analysis. Treatment effects on periodic annual volume growth were tested by ANOVA consistent with the randomized block design.

Results and Discussion

Analysis of covariance with initial Douglas-fir basal area as a covariate was suggestive of a significant positive treatment effect ($p=0.11$) (Figure 1). After adjusting for initial basal area, the average difference in growth between the control and treatment plots was ~9.6%. As a point of comparison, the same analysis performed on the data from the first two growing seasons was strongly insignificant ($p=0.61$).

The delayed response in growth improvement with treatment is similar to what was found following aerial Bravo fungicide applications (Mainwaring et al. 2002). Over the five year period of Bravo application, the cubic volume growth of treated stands increased ~35% versus untreated stands. In the final three years of application, the growth increase was ~60%, implying lack of response in the first two years of application. Because fungicides like Bravo and sulfur inhibit fungal infection/germination, and *P. gaeumannii* only infects newly expanding foliage (Stone et al. 2000), the explanation for this delay is the time required for a tree to build up enough uninfected foliage to enhance growth rates.

All plots showed substantial improvements in growth during the second two-year period compared to the first two-year period (Figure 2). This increase is probably attributable to greater growing season precipitation during the 2004 and 2005 growing seasons than during the 2002-03 period (Figure 3). Figure 3 indicates that the 2002-03 period growing season precipitation was abnormally low when compared to patterns during the previous 10 years.

Annual differences in spring moisture also appears to have affected foliage retention: Observations made by the lead author during foliage retention surveys on the ODF commercial thinning plots found that in many cases, trees retained fewer two-year old needles than three-year old needles, suggesting that the spring of 2003 was less favorable to fungal infection than the spring of 2004. This is logical, given the previously identified positive correlation between spring wetness and fungal germination rates (Manter et al. 2003). With both 2002 and 2003 having relatively low spring rainfall, the trees in this study might be expected to have experienced lower relative infection rates during the 2002-03 period than they would have during most two-year periods in the last 10 years. As a result, they have probably retained a greater amount of older foliage during the period following treatment, regardless of treatment type. Unfortunately, the improved conditions of the 2002-03 period coincided with the two years of fungicide application. If infection rates were lower during these treatment years, the positive effects of treatment would be smaller and harder to detect.

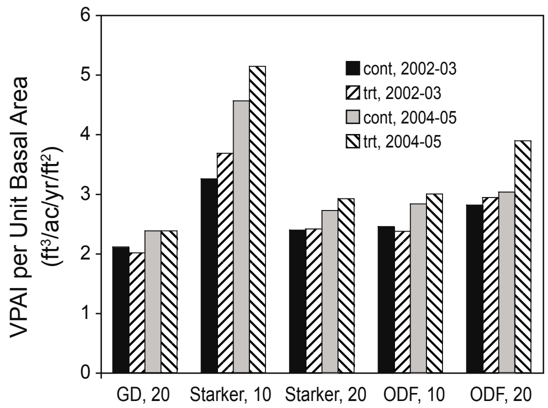


Figure 1 Periodic annual volume growth per unit basal area after sulfur application on five sites. Number after landowner refers to the initial age of the stand.

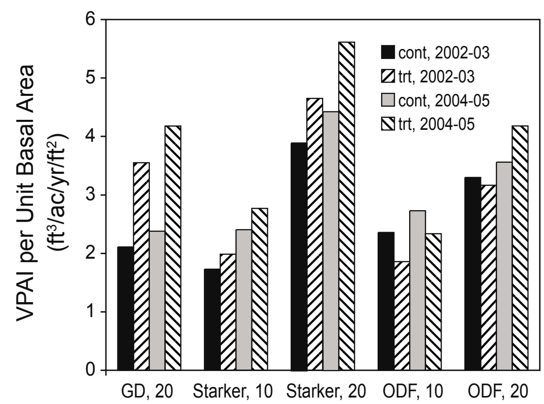


Figure 2 Periodic annual volume growth after sulfur application on five sites. Number after landowner refers to the initial age of the stand.

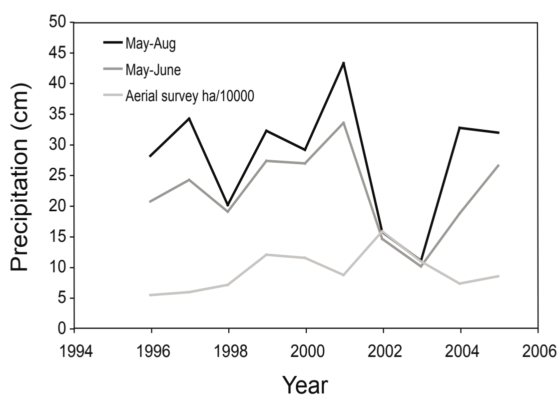


Figure 3 Measured precipitation at five Coast Range weather stations (Nehalem, Otis Junction, Seaside, Tillamook, Willamina) by year; SNC impacted hectares/10000 as identified by ODF aerial survey

Literature cited

Maguire, D., Stone, J., Mainwaring, D., Gourley, M., Kanaskie, A., and C. Moyer, 2004. Pp 57-58 in 2004 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Mainwaring, D., Kanaskie, A., and D. Maguire. 2002. Pp. 82-86 in 2002 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Manter, D. Reeser, P., and J. Stone. 2003. Pp. 47-57 in 2003 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Stone, J., Chastagner, G., and A. Kanaskie. 2003. Pp 40-46 in 2003 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Stone, J., Reeser, P., Sutton, W., and G. Chastagner. 2001. Pp 84-88 in 2001 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Stone, J., Winton, L., Reeser, P. Manter, D., Sutton, W., and E. Hansen. 2000. Pp. 13-19 in 2000 Annual Report, Swiss Needle Cast Cooperative, College of Forestry, Oregon State University, Corvallis, Oregon, USA.

Nutrient Limitations to Growth of Western Oregon Douglas-fir Forests: A Look Beyond Nitrogen

Doug Mainwaring, OSU, Doug Maguire, OSU; Steve Perakis, USGS; Rick Fletcher, OSU

Introduction

In 2006, the SNC Coop provided funds to augment the costs of a six-year fertilization trial aiming to test whether specific nutritional amendments might diminish or offset the effects of SNC. A second objective of this project is to test the growth response of individual trees to fertilization, whether or not they are infected with SNC: of the ten industrial forestland-owning participators, five have little or no SNC problems on their land base.

Progress to date is shown in Table 1. All sites have been identified (Figure 1) and plots are currently being established and measured. Soil is being collected and a tree climber has been collecting branches for foliage sampling.

Table 1: x = complete; y = partially complete

Landowner	Location	Treatments	Established	Measured	Soil sampled	Trees climbed
Cascade Timber	Waterloo	7	x			
Giustina	Pleasant Hill	5	x	y	y	x
Green Diamond	Eddyville	7	x	y	y	x
Green Diamond	Hemlock	7	x	y		
Hampton	Grand Ronde	7	y			
Hampton	Knappa	7	x	y		
Lone Rock	Drain	5	x			x
Menasha	Southport	7	x	y		x
Menasha	Coos River	7	x	y		x
Port Blakely	Chehalis	7	x	y	y	
Starker	Burnt Woods	7	y			
West Fork	Mineral, WA	7	x	y	y	
Weyco	Vernonia	5				
Weyco	Vernonia	5				

Treatments (Table 2) will be applied at all sites this winter, with the exception of the West Fork site in Mineral, WA. Because that site is at a relatively high elevation, we will need to apply material prior to snow accumulation (pre-Thanksgiving).

Table 2

Treatment	Material	Quantity
1 Control		
2 Nitrogen	Urea	200 lbs N/ac
3 Lime	Calcium carbonate	1000 lbs Ca/ac
4 Calcium	Calcium chloride	100 lbs Ca/ac
5 Phosphorus	mono-sodium	500 lbs P/ac phosphate
6 Kinsey	site-specific	
7 Fenn	site-specific	

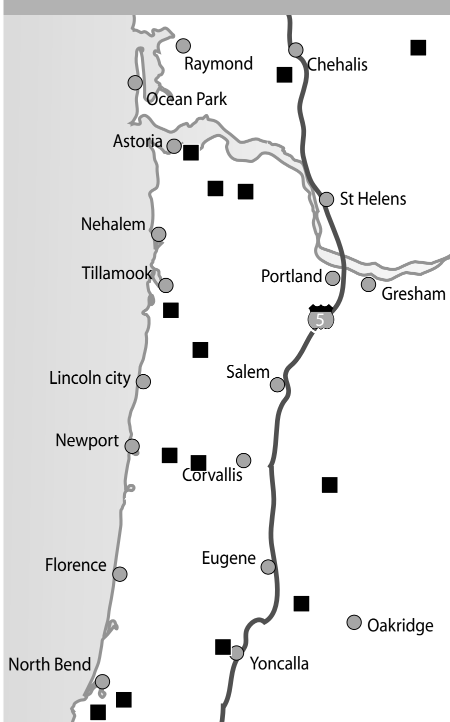


Figure 1. Treatment sites.

Influence of year on the relationship between foliage retention and branch biomass

Aaron Weiskittel and Doug Maguire

Oregon State University, College of Forestry

Introduction

The assessment of Swiss needle cast (SNC) severity relies on indices such as foliage retention that are correlated with the actual disease. Further, foliage retention has also been well correlated with both branch and tree foliage biomass (Weiskittel et al. 2006). The variability of this relationship, however, has yet to be determined.

Methods

In 1998 and 2004, multiple branch samples were obtained from the SNCC GIS permanent plot network. In both years, a southern most branch was obtained from the 5th whorl from the tree tip. The branch was assessed for foliage retention and clipped into foliage age classes, which were dried and weighed. A total of 83 and 219 branches were collected in 1998 and 2004, respectively.

Results

Sample branch diameters were not significantly different between 1998 and 2004. However, for a given branch size and location as well level of foliage retention, branch biomass was significantly higher in 2004 ($p<0.0001$). By foliage age class, the amount of 1- and 2-yr-old foliage were significantly higher in 2004, while no significant difference between years was detected for the 4-, and 5-yr old and older foliage. On the other hand, the 3-yr old foliage was actually significantly higher in 1998 ($p = 0.0124$). At a given branch size, branch location, and level of foliage retention, foliage biomass was higher in 2004 by 42 and 51% for the 1- and 2-yr-old foliage age classes, respectively, while 3-yr-old foliage was 30% greater in 1998 (Figure 1). Overall, foliage biomass was on average 37% higher in 2004 for a similar-sized branch with a moderate level of foliage retention in 1998.

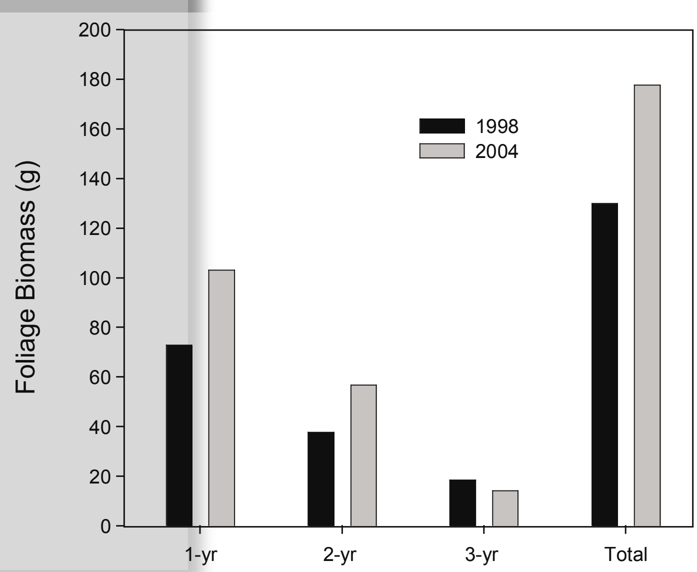


Figure 1. Predicted mean difference of foliage biomass (g) in the 1-, 2-, and 3-yr-old foliage age classes as well as total for a given branch size, branch location, and level of foliage retention between sampling years.

Discussion

This analysis indicates that foliage retention is not perfectly correlated with foliage biomass on a given branch as the relationship differs significantly between sampling years. This illustrates the primary drawback of solely relying on foliage retention as a measure of SNC disease severity. The difference between the two years was primarily in the first two foliage age classes. The results indicate that foliage density was much higher in the 1- and 2-yr-old foliage age classes in 2004. Hence, foliage retention gives a reasonable picture of foliage age class structure, but can not reliably provide an estimate of foliage density or total foliage biomass. Continuing to combine foliage retention measurements with estimates of crown sparseness is likely the best strategy for assessing the severity of SNC.

Literature Cited

Weiskittel, A.R., D.A. Maguire, S.M. Garber and A. Kanaskie 2006. Influence of Swiss needle cast on foliage age class structure and vertical distribution in Douglas-fir plantations of north coastal Oregon. Canadian Journal of Forest Research. 36:1497-1508.

Influence of Swiss needle cast on branch growth and mortality:

implications for individual tree growth projections

Aaron Weiskittel[1], Doug Maguire[1], and Robert A. Monserud[2]

[1]Oregon State University, College of Forestry, Department of Forest Science

[2] Pacific Northwest Research Station, United States Department of Agriculture Forest Service

Introduction

Swiss needle cast (SNC) influences many aspects of the crown including foliage age class structure and vertical distribution (Weiskittel et al. 2006a), maximum branch profile (Weiskittel et al. 2006b) and its overall size and shape (Weiskittel 2003). These previous studies, however, have examined the crown at one point in time and have consequently missed the dynamic nature of these changes. This effectively limits the capacity of these previous equations to assist in the prediction of individual tree growth. To address this deficiency, twenty-one crowns across a range of SNC severity were followed through time. From this data, dynamic individual branch growth and mortality were developed and incorporated into an annualized model of individual tree growth and yield.

Methods

Twenty-one trees in four SNCC installations were selected and initially measured in the summer of 2004. The installations were comprised of three PCT (Devitt, Jensen, & Simpson) and one GIS (#16) installation. On the PCT installations, the 100 TPA plot was measured at Devitt and the 200 TPA plot was measured at Jensen and Simpson, while the control plot was measured at all the installations. Within each plot, three trees were randomly selected from the 25^{th}, 63^{rd}, and 93^{rd} diameter percentile class. Each tree was then climbed and every branch (living + dead) from the 3^{rd} whorl from the tip to stem base was measured for height of insertation and diameter. All measured branches were also coded as either north or south. A subsample of branches were also measured for actual aspect, angle of insertation, total length, and non-foliated length and tagged for future reference. In the summer of 2006, the twenty-one trees were climbed again and all tagged branches were remeasured for growth and mortality.

The branch growth and mortality equations were annualized using the multi-level mixed-effects approach as described in Weiskittel et al. (in press). The influence of SNC was assessed by adding foliage retention and tree- and stand-level crown sparseness index to the final equation. CLSA was estimated using the sapwood taper equation of Maguire and Batistia (1996).

In addition, the effect of PCT was examined by adding an indicator variable. Finally, the equations were combined with the static crown reconstruction model of Weiskittel et al. (in review), the annual diameter and height growth equations of Weiskittel et al. (in press), and the annual mortality model of Flewelling and Monserud (2002). Using this system, growth was simulated on a subset of SNCC GIS and PCT permanent plots for four years and mean bias (observed – predicted) was assessed.

Results

Branch diameter growth showed a significant relationship with both crown sparseness at the individual tree- ($p<0.0001$) and stand-levels ($p<0.0001$) after accounting for initial branch size and location in the stem. In addition, branch diameter growth was significantly higher on whorl branches ($p<0.0001$). Foliage retention, measures of stand density, or PCT had no significant influence on branch diameter growth after accounting for these covariates. The final annualized model had the following form:

[1]

$$BDDG = \exp(2.3418 - 0.0546 * BD + 1.3471 * W + 0.0289 * BHT - 0.2044 * CLSA - 0.2894 * CLSA_{TOP})$$

where BDDG is branch diameter growth (mm yr^{-1}), BD is initial branch diameter (mm), W is an indicator variable for branch type (1 if whorl, 0 otherwise), BHT is branch height above ground (m), CLSA is individual tree crown sparseness, and $CLSA_{TOP}$ is mean tree crown sparseness for the 200 largest stems per ha. The equation had a R^2 of 0.37 and root mean square error of 1.05 mm yr^{-1}. The model suggests that branch diameter growth was reduced on plots with higher levels of SNC (Figure 1).

Branch mortality was significantly related to branch size ($p<0.0001$), whorl age ($p<0.0001$), tree diameter growth rate ($p=0.0022$), site index ($p<0.0001$), and stand-level crown sparseness ($p=0.0025$; Figure 2). After accounting for these variables, neither foliage retention nor PCT had a significant influence on branch mortality. The final annualized model had the following form:

[2]

$$P_M = \frac{1}{1 + \exp(27.2931 + 0.1045 * BD - 1.0207 * WAGE + 3.8699 * DGR - 0.3580 * SI - 0.8772 * CLSA_{TOP})}$$

where P_M is the annual probability of individual branch mortality, WAGE is the age of whorl, DGR is tree diameter growth rate (cm yr^{-1}) and all other variables have been defined above. The model indicates that branch mortality increased with whorl age, site index, and crown sparseness, but decreased with greater branch diameters and diameter growth rate. The equation explained 46% of the original variation in branch mortality.

Mean bias and mean square error for predicting individual tree 4-yr diameter and height growth using the equations of Weiskittel et al. (in press) as well as crown recession are given in Table 1. The use of the individual branch growth and mortality equations developed in this analysis were a significant improvement over the static height to crown base equation in predicting 4-yr crown recession. However, the diameter and height growth predictions were not improved and were even slightly poorer by the better prediction of crown base.

Table 1. Mean bias and mean square error after four years of simulation on several GIS and PCT plots using the annual diameter and height growth equations of Weiskittel et al. (in press). Crown recession was estimated using either a static HCB equation or individual branch equations developed in this study.

	Static HCB equation			Individual branch equations		
	DBH (n = 1532)	HT (n = 1077)	HCB (n = 1076)	DBH (n = 1532)	HT (n = 1077)	HCB (n = 1076)
Mean bias	-0.6958	-0.7061	-1.2332	-0.8493	-0.8467	0.2939
Mean square error	1.2409	0.8992	1.8294	1.3016	0.9765	1.3176

Discussion

Branch growth and mortality were significantly influenced by SNC in both thinned and unthinned plantations. The premature loss of foliage has decreased branch growth rates, while increasing branch mortality rates. These findings support the work of Weiskittel (2003) who suggested that maximum branch diameters were smaller throughout the crown and height to crown base was higher on trees with greater levels of SNC. The use of these developed dynamic equations improved predictions of crown recession across a range of SNC severity, but diameter and height growth predictions were not improved. This may be a simple result of the developed growth equations not directly accounting for the effects of SNC. For example, a similar crown ratio on a tree with high and low SNC is hardly the same thing because of the drastic loss of foliage caused by the disease. Hence, combining these individual branch equations with diameter and height growth equations that directly account for the effects of SNC may be a logical next step for predicting growth under varying levels of SNC.

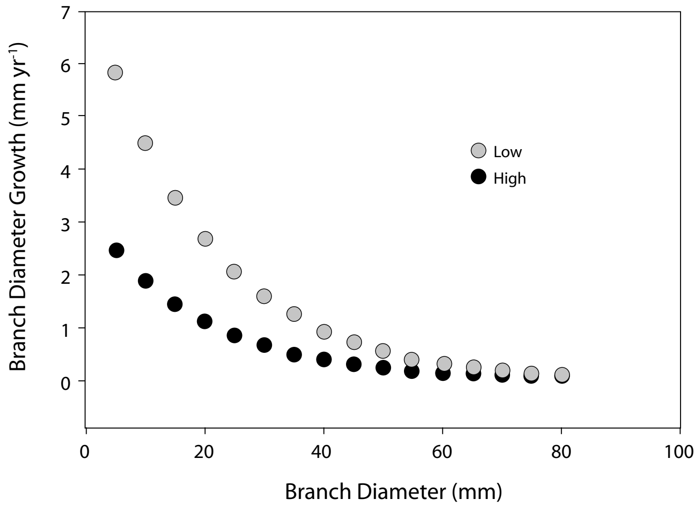


Figure 1. Predicted branch diameter growth (mm yr-1) using equation [1] for mid-canopy whorl branch on a tree with high and low SNC.

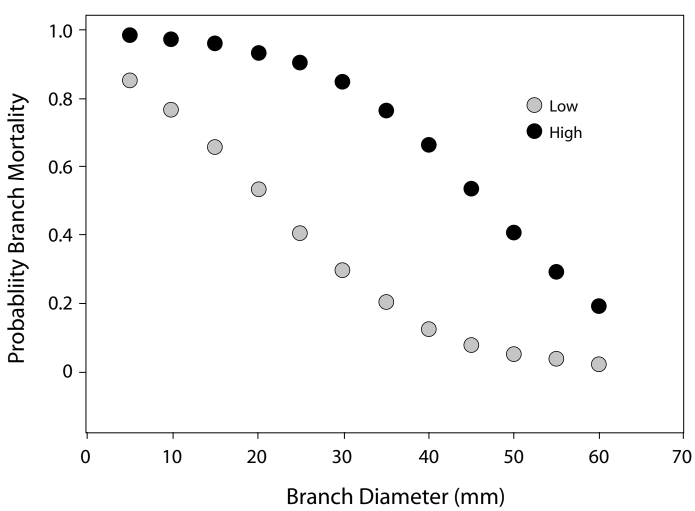


Figure 2. Predicted probability of annual branch mortality using equation [2] over branch diameter (mm) at a whorl age of 14 in stand with high and low SNC severity.

Literature Cited

Flewelling, J.W. and R.A. Monserud 2002. Comparing methods for modeling tree mortality. *In* Proceedings of the 2nd Forest Vegetation Simulator conference (RMRS-P-25) Eds. N.L. Crookston and R.N. Havis. USDA Forest Service Rocky Mountain Research Station, Fort Collins, CO, pp. 169-177.

Maguire, D.A. and J.L.F. Batista 1996. Sapwood taper models and implied sapwood volume and foliage profiles for Coastal Douglas-fir. Canadian Journal Forest Research. 26:849-863.

Weiskittel, A.R. 2003. Alterations in Douglas-fir crown structure, morphology, and dynamics imposed by the Swiss needle cast disease in the Oregon Coast Range. Oregon State University, Corvallis, OR, p. 389.

Weiskittel, A.R., D.A. Maguire, S.M. Garber and A. Kanaskie 2006a. Influence of Swiss needle cast on foliage age class structure and vertical distribution in Douglas-fir plantations of north coastal Oregon. Canadian Journal of Forest Research. 36:1497-1508.

Weiskittel, A.R., D.A. Maguire, R.A. Monserud, R. Rose and E.C. Turnblom 2006b. Intensive management influence on Douglas-fir stem form, branch characteristics, and simulated product recovery. New Zealand Journal of Forestry Science. 36:in press.

Weiskittel, A.R., D.A. Maguire and R.A. Monserud in review. Modeling crown structural responses to competing vegetation control, thinning, fertilization, and Swiss needle cast in coastal Douglas-fir of the Pacific Northwest, USA. submitted to Forest Ecology and Management.

Weiskittel, A.R., S.M. Garber, G.P. Johnson, D.A. Maguire and R.A. Monserud in press. Annualized diameter and height growth equations for Pacific Northwest plantation-grown Douglas-fir, western hemlock, and red alder. Forest Ecology and Management.

Influence of precommerical thinning on Douglas-fir branch attributes across a Swiss needle cast gradient

Aaron Weiskittel and Doug Maguire, OSU

Introduction

Precommerical thinning (PCT) has been shown to stimulate growth of the residual trees even under severe Swiss needle cast (SNC) (Maguire et al. 2004). In addition, PCT has significantly increased foliage retention, particularly in the middle and lower part of the crowns, four years after the treatments were applied (Maguire et al. 2003). This study sought to understand the influence of thinning and its interaction with SNC on upper crown branch attributes.

Methods

In the spring of 2005, five of the ten trees that have been annually assessed for SNC by Oregon Department of Forestry crews for the past six years were randomly selected for sampling in each plot of the 21 PCT installations. The trees were climbed and the southern-most branch on the 5th whorl from tree tip was clipped and transported back to the lab. The branch was measured for diameter (nearest 0.1 mm), total branch length (nearest 0.1 mm), foliated branch length (nearest 0.1 mm), maximum branch width (nearest 0.1 mm), and the total number of lateral branches. Following these measurements, the branch was clipped into five foliage age classes, dried for 48 hours at 85°C, and weighted to the nearest 0.01 g. The trends in branch attributes across the different thinning treatments were analyzed using linear mixed effects models after accounting for branch size and foliage retention.

Results

Branch size ($p = 0.0251$) and total foliage mass ($p = 0.0130$) were significantly greater on branches on the heavily thinned PCT plot (100 TPA) when compared to the control. On the 100 TPA plots, median branch size was estimated to be between 1.01 and 1.28 times greater than the control, while total foliage mass was, on average, 8.7% greater. The response of total foliage mass, however, was dependent on the interaction of branch size and treatment. This interaction indicated that branch total foliage mass increased in the 100 TPA when compared to the control up to a branch size of 20 mm and then, steadily decreased with respect to the control. Although absolute mass in a given foliage age class was not influenced by PCT, both the relative amount of foliage in the 1- ($p = 0.0420$) and 2- ($p = 0.0022$) year old foliage age classes was significantly increased in the 100 TPA treatments. For the 200 TPA treatment, there was only moderate evidence that the relative amount of foliage in the 1-year-old foliage age class was significantly increased ($p = 0.0562$).

For a given branch size and installation, branch length, foliated branch length, the number of lateral branches, and foliage retention were not statistically different across treatments. Both treatments did have a significant influence on maximum branch width (p = 0.0015) and elongation of the primary branch (p = 0.0015). On average, maximum branch width was 0.83 and 0.92 times smaller than the control for the 100 and 200 TPA treatments, respectively. Elongation of the primary branch was 1.29 and 1.11 times greater in the 100 and 200 TPA treatments, respectively.

Discussion

This study indicated that upper-crown branches were sensitive to changes in stand density imposed by PCT regardless of SNC severity. Increases in branch size and elongation are similar to increases in tree diameter and height growth. The influence of heavy thinning on branch foliage biomass in this study differ from that reported by Brix (1981). In his study, branch foliage biomass on a mid-crown branch was increased by nearly 60% five years after thinning. Branch total foliage biomass in the 100 TPA treatment of this study was only significantly increased up to 20 mm and decreased thereafter.

Following thinning, Shibuya et al. (2005) found a younger mean needle age in thinned trees when compared to the control. Although PCT had no significant influence on either branch foliage retention or absolute foliage mass in a given age class, there was evidence that 1-year-old needles made up a greater proportion of the branch foliage biomass in the 100 and 200 TPA treatments. This would imply a similar conclusion to Shibuya et al. (2005) for upper crown branches in Douglas-fir. The lack of a thinning effect on the number of lateral branches and an increased elongation rate are similar to the results of Brix (1981).

Literature cited

Brix, H. 1981. Effects of thinning and nitrogen fertilization on branch and foliage production in Douglas-fir. Canadian Journal of Forest Research. 11:502-511.

Maguire, D., A. Kanaskie and D. Mainwaring 2003. Trends in symptom severity after precommerical thinning in Douglas-fir stands with differing initial Swiss needle cast severity. *In* Swiss needle cast research cooperative 2003 annual report Ed. G. Filip. Oregon State University, College of Forestry, Corvallis, OR, pp. 23-24.

Maguire, D., A. Kanaskie and D. Mainwaring 2004. Growth responses to pre-commercial thinning under differing levels of initial Swiss needle cast severity in north coastal Oregon. *In* Swiss needle cast cooperative 2004 annual report Ed. D. Mainwaring. Oregon State University College of Forestry, Corvallis, OR, pp. 28-30.

Shibuya, M., H. Hasaba, T. Yajima and K. Takahashi 2005. Effect of thinning on allometry and needle-age distribution of trees in natural *Abies* stands of northern Japan. Journal of Forest Research. 10:15-20.

Influence of sulfur and sulfur+lime on Douglas-fir upper crown branch attributes

Aaron Weiskittel and Doug Maguire

Dept. of Forest Science, Oregon State University College of Forestry

Introduction

Sulfur applications have been shown to offer some potential for ameliorating Swiss needle cast (SNC) after recent operational applications. Although sulfur has been shown to significantly reduce SNC infection levels (Stone et al. 2005), neither a tree basal area nor height growth response has been shown (Maguire et al. 2004). In addition, specific leaf area has also showed no significant change to this treatment (Weiskittel and Maguire 2005). However, it has been hypothesized that total foliage mass may have to continue to build back up for several more years until tree growth responds to the sulfur treatments. This study sought to understand the influence of these treatments on several branch attributes including total foliage mass and foliage age class structure.

Methods

One south-facing sample branch was collected from the 5th whorl from tree tip on 30 trees that were previously treated on a Starker Forest plantation. Ten trees were selected randomly from each treatment, namely: (1) control; (2) sulfur; and (3) sulfur + lime (Table 1). The branches were returned to the laboratory, stored in a freezer until processing, and clipped into 5 foliage age classes. The foliage was dried for 48 hours, separated from the branch woody components, and weighed to the nearest 0.01 g.

Table 1. Attribute of the sample trees from which branches were taken by treatment.

Attribute	Mean	Standard deviation	Minimum	Maximum
Control (n = 10)				
DBH	9.8	0.9	7.5	10.8
HT	21.99	1.22	19.55	23.51
HCB	9.78	1.09	7.57	11.70
Sulfur (n = 10)				
DBH	9.8	1.2	7.6	11.1
HT	22.45	1.26	20.39	24.10
HCB	10.13	1.36	7.44	11.55
Sulfur + Lime (n = 10)				
DBH	10.3	1.7	7.6	14.0
HT	22.41	1.19	20.61	24.20
HCB	9.95	1.84	6.89	12.70

Branch attributes examined in this analysis include branch diameter (mm), branch length (mm), foliated branch length (mm), number of secondary lateral branches, foliage retention, total foliage mass, and foliage by age class. Analysis of covariance was used to assess the treatment effects after accounting for branch size and location as well as tree size.

Results

The treatments showed a significant relationship with branch diameter and total foliage biomass after accounting for the necessary covariates. For a given branch location and tree size, branch diameter was 11.9% larger for the sulfur + lime treatment when compared to the control ($p = 0.0361$). There was no significant difference in branch diameter between the sulfur only treatment and the control. Also, for a given branch location and tree size, branch total foliage biomass was 37.1% higher for the sulfur + lime treatment when compared to the control ($p = 0.005$; Figure 1). There was no significant difference in branch total foliage biomass between the sulfur only treatment and the control. The relationships of the treatments to all other dependent variables examined in this analysis were highly insignificant.

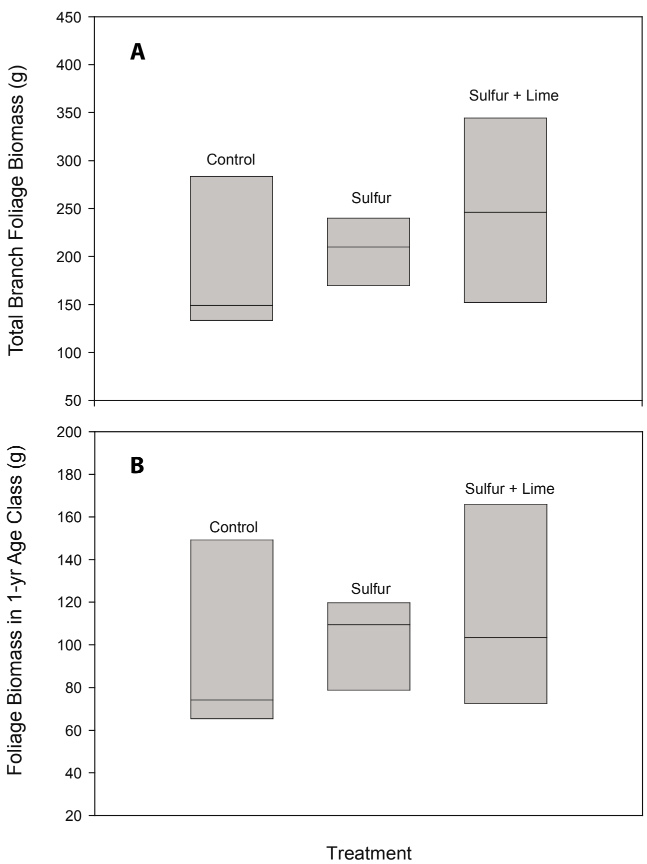


Figure 1. Boxplots of total foliage biomass (A) and foliage biomass in the 1-yr age class (B) by the treatments. The bar in the middle of the box is the median for that particular treatment.

Discussion

Based on this analysis, there is significant evidence that the sulfur + lime treatment may increase foliage biomass at the whole tree by increasing both branch diameter and the amount of foliage on a branch of a given size. The increase in this foliage mass, however, could not be significantly attributed to one particular foliage age class. Based on the larger branch sizes, it appears that greater branch growth and an implied increase in the younger foliage age classes may be driving the relationship rather than enhanced foliage retention. This is further supported by that lack of a statistically significant relationship between treatment and observed foliage retention. The display of this foliage is similar between treatments as branch length, foliated branch length, and the number of higher order lateral branches were unaffected.

Literature Cited

Maguire, D., Stone, J., Mainwaring, D., Gourley, M., Kanaskie, A., and Moyer, C. 2004. Growth response to sulfur application in Douglas-fir stand with Swiss needle cast. *In:* Mainwaring, D. Swiss needle cast 2004 annual report. Oregon State University College of Forestry. Corvallis, OR. pp 57-58.

Stone, J., Chastagner, G., and Kanaskie, A. 2005. Control of Swiss needle cast in forest plantations by aerially applied elemental sulfur fungicide. *In*: Shaw, D. and Mainwaring, D. Swiss needle cast 2005 annual report. Oregon State University College of Forestry. Corvallis, OR. pp 12-17.

Weiskittel, A. and D. Maguire. 2005. Influence of intensive management and sulfur treatments on Douglas-fir foliage. *In*: Shaw, D. and Mainwaring, D. Swiss needle cast 2005 annual report. Oregon State University College of Forestry. Corvallis, OR. pp 21-22.

Taper and volume responses of Douglas-fir to aerially applied sulfur and nutrients for control of Swiss needle cast disease

Nicole Younger, Temesgen Hailemariam, and Sean Garber, Oregon State University

Abstract

Volume, taper, and selected tree attributes were examined on 120 Douglas-fir (*Pseudotsuga menziesii*) trees for responses to treatments of 1) sulfur, 2) a sulfur and nutrient treatment, or 3) a control, which received no treatment. Tree attributes such as crown ratio, crown width, and sapwood area at crown base showed no statistically significant differences between treatments (p= 0.26, 0.93, and 0.09 respectively). Taper analysis was conducted using a modified Kozak's (1988) variable exponent model form, and determined that the taper on trees within the sulfur treatment was not significantly different from the taper of the control treatment (p = 0.09). However, the sulfur + nutrient treatment showed an improved taper compared to the control (p = <0.0001). Unfortunately, this improvement in taper in the sulfur + nutrient stand has not translated into a significant increase in cubic foot volume removed in the first thinning after adjusting for tree size differences between treatments (p = 0.3441). Comparing treatments by dollar value of removed trees in the first thinning also showed no significant differences, thereby implying that sulfur as well as sulfur + nutrient treatments are not able to increase volume enough in four years to produce additional profits in the first thinning.

Introduction

Swiss needle cast (SNC) has been shown to not only reduce growth but also alter crown dynamics (Weiskittel 2003). Weiskittel and Maguire (2004) found that foliage retention (which is strongly related to SNC severity) had a significant effect on stem taper. They discovered that for a given tree diameter at breast height (dbh) and relative height, a reduction in foliage retention significantly reduced diameter inside bark throughout the stem, except below breast height, thereby increasing the amount of taper in a tree with poor needle retention.

In a direct attempt to combat SNC, several recent studies have found that sulfur, which acts as not only a nutrient but also a fungicide, can decrease the incidence of SNC and improve foliage color and retention (Stone *et al.* 2004, Chastagner 2002). Elemental sulfur, despite it's recent popularity, is actually man's oldest fungicide. Recent discoveries by Williams and Cooper (2003) have revealed that many plants, including tomato, cotton, tobacco, and French bean, actually hold sulfur in their xylem for an induced defense response against certain types of fungi. The nutritional value of sulfur has been underestimated in the past as well. In the soil, sulfur (SO_4) plays a pivotal role in the movement of acidic cations such as H^+, and Al^{3+}, as well as nutrient cations such as Ca^{2+} and Mg^{2+} (Johnson and Mitchell 1998). The increased use of fertilizers that contain little or no sulfur and the decrease in atmospheric sulfur deposition from reduced industrial emissions have resulted in an increasing soil sulfur deficiency worldwide (Jasinski et al. 1999). Because there should be a constant ratio of 0.030 on a gram atom basis between organic S and total N in the foliage of conifers (Turner et al. 1979, Kelly and Lambert 1972), the Oregon Coast Range, being naturally rich in available nitrogen, has actually aggravated a sulfur deficiency in many regions. It is not uncommon for Douglas-fir to exhibit a growth response to an N and S treatment, but not to an N treatment alone (Garrison et al. 2000). Analogous responses have also been observed in other conifers (Yang 1998, Brockley 2000).

Most importantly, sulfur has been proven safe for aerial application in forests. The 2005 Material Safety Data Sheets (Baker 2004) claim sulfur is "considered essentially non-toxic by ingestion", and "is not expected to be toxic to aquatic life". It is here hypothesized that aerial application of sulfur for consecutive years may be able to decrease the amount of taper, thereby increasing the diameter at the small end of logs taken out during the first thinning in the Oregon Coast Range.

The objective of this research is to determine if tree crown and stem allometrics of Douglas-fir differ after four years of sulfur and sulfur + nutrient treatments. Specific objectives are to: 1) test the influence of sulfur and sulfur + nutrient treatments on sapwood area, crown ratio, and crown width; 2) test for stem taper differences among the treatments using a variable exponent taper model; and 3) compare cubic-foot volumes and tree values removed in the first commercial thinning among treatments.

Methods

Study site

A Douglas-fir plantation located in the Nelsen Creek drainage of the Oregon Coast range was selected by Starker Inc. in 2000 due to it's fairly severe infection of Swiss needle cast disease, it's representation of typical Douglas-fir plantation management, and the fact that is was planted using a single source of Douglas-fir stock. This site is located at 44º 43´ N, 123º 44´ W, in Lincoln County at approximately 530 feet in elevation with 5 – 10 percent slope. The soil is a Preacher-Bohannon-Slickrock complex. Bohannon and Slickrock are gravelly loams, whereas Preacher is a clay to sandy loam. Bedrock is located 35 to 58 inches below the surface. According to the Soil Survey of Lincoln County Area, Oregon (National Cooperative Soil Survey 1997) Douglas-fir is considered suitable for timber production in these soils.

Three units, approximately two square acres each, were delineated from the rest of the plantation. Each of these three units were randomly assigned a treatment of either; 1) sulfur, 2) sulfur + nutrients, or 3) no treatment. The sulfur treatment consisted of 10 gal/acre of liquid sulfur, 20 gal/acre of water and 8 oz. of tactic per 100 gallons. This sulfur treatment was aerially applied twice in June 2002 and twice again in June of 2003. The nutrient treatment was formulated specifically for this site and included calcium, dolomite, sulfur, potassium, boron, ferrous sulfate, copper sulfate, zinc sulfate and urea and was applied annually 2000 - 2004. Specific concentrations, spray rates, and spray years are given in Table 1.

Experimental design

The treatment sites were established in 2000 as part of a longer term non-destructive study. Because the stand was due for the first commercial thinning, forty trees per treatment, which showed no significant defect, such as forks or conks, were selected at random and felled before the 2005 growth year began, and used in the taper analysis (Table 2). The stand was 22 years old and had a density of 407 trees per acre and a basal area of 203 ft^2/acre at the time of felling. This completely randomized experimental design faults in that there is technically only one replication because the experimental unit is actually the two-acre treatment block. To make the statistical analysis possible, each tree will be treated as if it is an experimental unit. It should be kept in mind that all conclusions taken from this study are essentially from a single replication, and the scope of inference applies only to this stand in the Oregon Coast Range.

Table 1: Concentrations and per acre rates of components in the sulfur + nutrients treatment by year.

	Year					
Nutrients	2000	2001	2002	2003	2004	Total
Calcium (CaCO3)	540	540	540		1000	2620 lbs
Doloprill	1440	1440	1440			4320 lbs
Sulfur (90 - 92%)	25				35	60 lbs
Potassium (0-0-50)	250				300	550 lbs
Boron (14.3%)	15				15	30 lbs
Ferrous Sulfate (26%)	270					270 lbs
Copper Sulfate (23%)	10				15	25 lbs
Zinc Sulfate (36%)	20				10	30 lbs
Urea (46-0-0)	440					440 lbs
Sulfur						
Liquid Sulfur w/ tactic				20	20	40 gallons

Table 2: Minimum (Min), maximum (Max), mean, and standard deviation (Std. Dev.) of selected tree attributes. n = 120 trees.

	Min	Max	Mean	Std. Dev.
Total ht (ft)	55.5	86	70.6	5.28
dbh (in)	4.1	13.2	8.2	1.7
Crown Ratio (%)	28.8	71.0	48.2	7.8
Crown Width (ft)	2.1	14.5	8.8	1.9
Sapwood Area (sq. inch)	1.5	58.4	18.5	9.5

Data collection

Before removing any disks, branches (except the lowest live branch) were removed from the 120 felled trees and a cloth tape was laid on the length of the bole to measure tree height from the butt of the log to the tip of the terminal bud. Stump height was then recorded and added to tree height as well as disk heights, to obtain total heights. The height of each disk (h_i) was then marked on the tree by taking out a small chunk of bark with an axe and measuring to the bottom side of the mark with the cloth tape. Approximately 9 disks were taken per tree; 1) stump height (approximately six inches to one foot from ground), 2) breast height, 3) crown base, and 4) approximately six disks that fell between every third whorl above dbh. These last six disks were taken at interwhorls (half way between every third whorl) to avoid complications with whorl swell. The cloth tape was then removed and a chainsaw was used to remove disks so that the bottom of the disk aligned with the previously mentioned axe mark. The top of the disk was then labeled by plot number, tree number and disk number and all disks from one tree were placed into a plastic garbage bag for transport to the lab. In addition, diameters at 19, 38, and 57 feet above stump height were measured to the nearest tenth of an inch to produce the small end diameters of the 19 foot logs that would have been taken from the tree in a thinning. On each of the collected disks, two perpendicular measures of diameter inside and outside bark were taken to the nearest millimeter and then averaged. To obtain a sapwood area measurement, four radii measurements of heartwood were taken per crown base disk to the nearest millimeter. Sapwood area was indirectly obtained by subtracting heartwood surface area from total diameter inside bark surface area, assuming that the heartwood is circular in shape.

Crown ratio was defined as the measured distance between crown base to top of terminal leader divided by total tree height, where crown base is defined as the point on the bole where the lowest living branch exists. Two perpendicular branches from the whorl containing the lowest live branch were measured for crown width to the nearest tenth of an inch and then averaged to obtain crown width per tree.

Analysis

A one-way analysis of covariance was used to test for differences in sapwood area, crown ratio, and crown width among the treatments. Because sapwood area is often considered to be directly proportional to tree leaf area (Shinozaki et al. 1964, Waring et al. 1982), it was used to determine if sulfur treatments could improve the leaf area of these infected crowns. When necessary, the response variable was transformed with a natural logarithm to stabilize the variance. For each attribute a selection of covariates were tested for additional explanation of variance; the one or two which explained the most variation were used in the final analysis. The generalized linear model procedure in SAS version 9.1 was used to conduct the one-way analysis of covariance (SAS Institute, Inc.).

Kozak's (1988) variable exponent taper equation was used to explore the effect of treatment on stem taper. The original model can be written as:

$$d_i = a_0 dbh^{a_1} a_2^{dbh} X^{b_1 Z^2 + b_2 \ln(Z+0.001) + b_3 \sqrt{Z} + b_4 e^Z + b_5 (dbh / H)}$$

Where d_i, the dependent variable, is diameter inside bark at a particular height (h_i) on the tree bole, dbh is diameter outside bark at breast height, Z is relative height (h_i/H) where H is total height, and X is $(1-\sqrt{h_i / H})/(1-\sqrt{p})$. The inflection point, p, is the relative height at which the tree shape changes from a neiloid to a paraboloid and $a_0 - a_2$ and $b_1 - b_5$ are parameters to be estimated.

To test for treatment effects, two treatment indicators were added to the variable exponent portion of the model, these being I_S and I_{SN}, where I_S equals one if the trees are sulfur-treated, zero otherwise, and I_{SN} equals one if the trees are sulfur-and-nutrient-treated, zero otherwise.

Data sets used to develop taper equations inherently contain autocorrelation. Ignoring correlated errors is a valid option, yet this option results in: (1) estimators which no longer have a minimum variance property, (2) underestimation of the mean square error and standard errors of parameter estimates, and (3) unreliable statistical tests using t or F distributions, as well as unreliable confidence intervals (Kozak 1997). Because an accurate estimation of standard error for the treatment coefficient was essential to this analysis, the autocorrelation was accounted for with a combination of a continuous autoregressive error structure (CAR(1)) and a random tree effect (a nonlinear mixed effects technique). These techniques have repeatedly been proven effective for providing meaningful tests of significance in modern taper analyses (Garber and Maguire 2003, Williams and Reich 1997, Tasissa and Burkhart 1998). Evaluation of assumptions for testing parameters were assessed with residual and empirical autocorrelation plots at α = 0.05 (Pinheiro and Bates 2000). Nested models were compared using likelihood ratio tests, and included tests on random effects, variance functions, and correlations structures (Pinheiro and Bates 2000, Garber and Maguire 2003). Models were fitted with S-PLUS 7.0 (Insightful Corp.).

The Smalian's formula was used to estimate the cubic foot volume of the 19-foot logs that would have been taken in a thinning, had these trees not been used for taper analysis. Smalian's formula can be written as:

$$\frac{\left(DIBSE + DIBLE\right)}{2} * L$$

where DIBSE is the diameter inside bark at the small end, DIBLE is the diameter inside bark at the large end and L is the log length, which is 19 feet in this case. Cubic foot volume was calculated by log in each treatment up to a diameter of 4 inches inside bark. All trees produced two logs above stump height, while few produced three. An analysis of covariance was performed after a log transformation of the cubic foot volume to correct a strong non-constant variance. A dbh covariate was incorporated to adjust for tree size; this was necessary since the subject trees were randomly selected at each plot, and average tree size was slightly different, but not statistically so, between treatments (Control-Sulfur p-value = 0.6556, Control-Sulfur + nutrient p-value = 0.6648, Sulfur-Sulfur + nutrient p-value = 0.9898).

To monetarily quantify volume differences between treatments, Scribner board foot volume was also determined for each tree. Board foot volumes were calculated based on a 1972 Scribner factor table to the nearest inch diameter (Bell and Dilworth 2002). Whenever possible a 19-foot saw log will be taken to a 5" DIBSE, and what is left will be cut into 19-foot pulp logs down to a 2" DIBSE. Dollar values were obtained from the Oregon Department of Forestry Region 1, 2006, 2nd quarter log price report. Saw logs, assumed to all be 3-saw quality (5 – 7"), were listed as having a pond value of $595 per MBF while the pond value of pulp logs (utility) is $55 per MBF.

Results

Crown attributes

An analysis of the sapwood data revealed that the sulfur treatment has 1.05 times more sapwood than the control (95% confidence interval 0.95 – 1.16) while the sulfur + nutrient treatment has about the same sapwood area as the control (.99 times more than control, 95% CI = 0.90 – 1.10). Statistically, neither of these were significantly different from the control (p = 0.94 and 0.67 respectively) and the sulfur treatment was not significantly different from the sulfur + nutrient treatment (p = 0.32).

After adding a total height covariate (which account for 21% of variation) in the crown ratio model, mean crown ratios were 50, 47, and 48% for the control, sulfur, and sulfur + nutrient treatments, respectively. Neither of the treatments are significantly different from the control (control – sulfur comparison p-value = 0.14, control – sulfur + nutrient comparison p-value = 0.16).

The sulfur and control treatments had a mean crown width of 8.9 ft, while the sulfur + nutrients treatment had a width of 8.5 ft. Of all possible covariates sapwood area accounted for the most variation in crown width (29%). Similar to sapwood area and crown ratio, the treatment comparisons indicate no statistical significance (control – sulfur comparison p-value = 0.51, control – sulfur + nutrient comparison p-value = 0.85).

Taper

To properly be able to draw conclusions about the effect of sulfur and sulfur + nutrients on taper, Kozak's (1988) taper model was refined. The α_2 parameter which helps to describe inside bark diameter from DBH was eliminated due to very high parameter correlations and an insignificant *p*-value. The redundancy of the Z variable in the exponent parameters b_2, b_3, and b_4 led to an examination of the necessity of all three of these parameters. It was determined that eliminating the b_2 parameter improved the AIC, BIC as well as the log likelihood ratio, and further analysis was conducted without the b_2 parameter. The final model form can be written as:

$$d_i = a_0 \mathbf{DBH}^{a_1} \quad X^{b_1 Z^2 + b_3 \sqrt{Z} + b_4 e^z + b_5 \left(\mathrm{DBH}/\mathrm{H}\right) + b_6 \mathrm{I_S} + b_7 \mathrm{I_{SN}}}$$

Because error increased with diameter of tree disks, the assumption of constant variance was initially violated. This was corrected for with a weighted power function of 0.3, which significantly improved the fit of the data (p = < 0.0001). All following models discussed here contain this same weighting function. In determining the best taper modeling technique, Akaike's Information Criterion (AIC), Bayesian

Information Criterion (BIC), as well as the log likelihood are presented between models with and without a random effect and a CAR(1) (Table 3). A first-order autoregressive process was found to be adequate in accounting for the significant autocorrelation, causing an addition of a random tree effect to not significantly account for the remaining autocorrelation.

Table 3: Akaike's Information Criterion (AIC), Bayesian Information Criterion (BIC) and log-likelihoods are presented between taper models with and without a random effect and a CAR(1).

Error Structure[a]	Parameters	Estimated AIC	BIC	Log Likelihood
GNLS	10	8428	8478	-4204
GNLS with CAR(1)	11	7955	8009	-3966
NLME	11	8342	8397	-4160
NLME with CAR(1)	12	7958	8018	-3967

[a] GNLS: generalized nonlinear least squares model without a correlation structure or random tree effect; CAR(1): continuous autoregressive error structure with a lag of one; NLME: nonlinear mixed effects model fit by maximum likelihood with a single random tree effect.

Tests on the two indicator variables suggested that the taper in the sulfur treatment was not statistically different from the control (e.g., b_6 was not significantly different from zero, p = 0.7160). However, the sulfur + nutrient treatment did have significantly less taper than the control treatment indicated by b_7 being significantly less than zero (p = 0.0246). Because the sulfur + nutrient treatment shows a significantly improved taper, using a different set of taper coefficients is suggested (Table 4, Figure 1).

Volume and valuation

Cubic foot volume, as quantified by Smalian's formula, to a 4-inch inside bark diameter, showed no significant differences among the treatments. After correcting for tree size with dbh, the control treatment had a mean tree volume of 12.08 ft^3, the sulfur treatment had a mean of 11.19 ft^3, and the sulfur + nutrient treatment had a mean of 11.59 ft^3 (control-sulfur comparison p-value = 0.0957, control-sulfur + nutrient comparison p-value = 0.3441).

Because smaller diameter logs are worth depreciably less than saw logs, values were calculated per tree using the aforementioned dollar prices. Much like the previous volume results, this log valuation revealed no treatment differences in dollar values of thinned trees after accounting for tree size with a dbh covariate (control – sulfur comparison p-value = 0.6850, control-sulfur + nutrients comparison p-value = 0.6969). Surprisingly, the control treatment actually had the greatest mean dollar value ($ 25.98) although, this is not statistically significantly different from the other two treatments, where the average value of a sulfur treated tree is $25.32, and a sulfur + nutrient treated tree is $25.35.

Table 4: Taper model coefficients with corresponding standard errors listed for the two significantly different treatments; control and sulfur + nutrients.

Control Treatment			Sulfur and Nutrient Treatment		
Parameter	Estimate	Std. Error	Parameter	Estimate	Std. Error
a_0	1.0609	0.1177	a_0	1.8422	0.3506
a_1	0.9442	0.0203	a_1	0.8427	0.0354
b_1	0.1403	0.0834	b_1	0.3942	0.1293
b_3	-1.1015	0.1011	b_3	-1.1917	0.1306
b_4	0.6266	0.0565	b_4	0.5599	0.0881
b_5	0.0132	0.0042	b_5	0.0180	0.0077

Discussion

Sapwood area at crown base was hypothesized to be greater in the sulfur treated stands due the increase in foliage retention and a concurrent increase in leaf area; this however, was not observed. Neither the sulfur, nor the sulfur + nutrient treatment showed a statistically significant increase in sapwood area. This may be due to a delay in the amount of time required for an increase in leaf area to show itself in sapwood area. This may also be related to changes in sapwood anatomy after fertilization improving conductivity, such as decreases in ring density, percent latewood, and increases in lumen diameter (Jozsa and Brix 1989; Mäkinen et al. 2002).

There was a slight, albeit insignificant, decrease in crown ratio in the treated stands. There was also no apparent effect on crown width. These results were not unexpected. The impact of SNC on these gross measures of crown

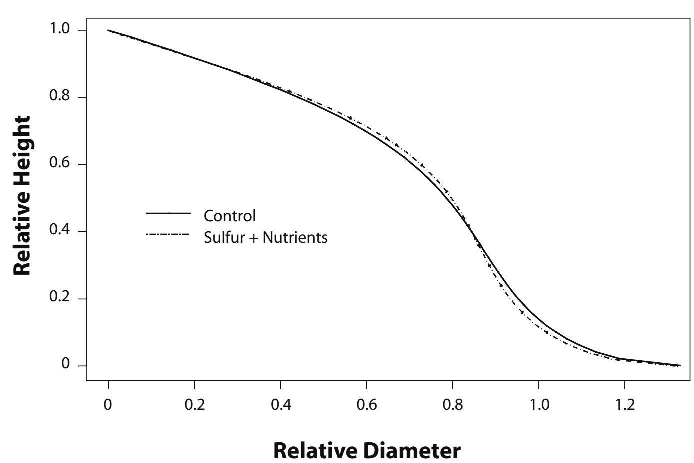


Figure 1: Graphical display of taper difference between the control and sulfur + nutrients treatments.

size has been shown to be very minimal – slightly increasing crown recession and increasing crown profile in the lower crown third (Weiskittel 2003). The decrease in crown ratio may reflect a slight fertilization effect (Albaugh et al., in press).

After finding no significant changes in crown attributes between treatments, it is surprising to find that the sulfur + nutrient treatment actually decreased taper. Since the pathogen infects the most productive current year needles which are skewed to the top of the tree (Weiskittel et al. 2006), area increment reduction is greatest at upper stem portions relative to healthy trees (Weiskittel and Maguire 2004). The effect of the sulfur + nutrients ameliorates this growth impact resulting in vertical stem increments similar to healthier trees, resulting in less taper.

The financial justification for sulfur treatments in SNC infected stands was expected to partially come from an increase in volume produced in the first commercial thinning. The proven improvement of taper in the sulfur + nutrient treatment was hoped to cause more 19-foot logs to move into the saw log category which brings approximately ten times the dollar value than the pulp logs. However, both the cubic foot results as well as the monetary results revealed no significant differences between treatments implying there is no volume benefit to the sulfur nor the sulfur + nutrient treatments. These treatments simply did not improve small end diameter enough to produce a significant difference after just four years of nutrient application and two years of sulfur. This insignificance could be due to a lack of a sufficient time period for the increased growth rate to reveal itself in total volume, but whether the DIBSE will improve enough in the next couple of years to receive a total volume benefit remains to be seen.

Acknowledgments

We thank Starker Forests Inc. of Corvallis, Oregon for their insights and monetary support, particularly Mark Gourley of Starker for installing and maintaining the project.

Literature Cited

Albaugh,T.J., H.L.Allen, and T.R. Fox. 2006. Individual tree crown and stand development in Pinus taeda under different fertilization and irrigation regimes. For. Ecol. Manage. (In press)

Baker, J.T. 2004. Material safety data sheet: Sulfur. Phillipsberg, NJ. 7 p.

Bell, J.F. and J.R Dilworth. 2002. Log scaling and timber cruising. Cascade Printing Co. Corvallis, OR. 439p.

Brockley, R.P. 2000. Using foliar variables to predict the response of lodgepole pine to nitrogen and sulfur fertilization. Can. J. For. Res. 30:1389-1399.

Chastagner, G. 2002. Fungicidal Management of Swiss needle cast: progress report. P. 65 – 69 in Swiss Needle Cast Cooperative annual report. Filip, G. (Ed.). College of Forestry, Oregon State University: Corvallis, OR.

Garber, S.M., and D.A. Maguire. 2003. Modeling stem taper of three central Oregon species using nonlinear mixed effects models and autoregressive error structures. For. Ecol. and Manage. 179:507-522.

Garrison, M.T., J.A. Moore , T.M. Shaw, and P.G. Mika. 2000. Foliar nutrient and tree growth response of mixed-conifer stands to three fertilization treatments in northeast Oregon and north central Washington. For. Ecol. and Manage. 132:183-198.

Jasinski, S.M., D.A. Kramer, J.A. Ober, and J.P. Searls. 1999. Fertilizers-sustaining global food supplies. USGS fact sheet FS-155-99.

Johnson, D.W. and M.J. Mitchell. 1998. Responses of forest ecosystems to changing sulfur inputs. P. 219-262 in Sulfur in the Environment, Maynard, D. (ed.). Marcel Dekker, Inc., New York, NY

Jozsa, L.A. and H. Brix 1989. The effects of fertilization and thinning on wood quality of a 24-year-old Douglas-fir stand. Can. J. For. Res. 19: 1137-1145.

Kelley, J., and M.J. Lambert. 1972. The relationship between sulfur and nitrogen in the foliage of Pinus Radiata. Plant and Soil 37:395-407.

Kozak, A. 1988. A variable-exponent taper equation. Can. J. For. Res. 18:1363-1368.

Kozak, A. 1997. Effects of multicollinearity and autocorrelation on the variable-exponent taper functions. Can. J. For. Res. 27:619-629.

Mäkinen, H., P. Saranpää, and S. Lunder. 2002. Wood-density of Norway spruce in relation to nutrient optimization and fibre dimensions. Can. J. For. Res. 32: 185-194.

National Cooperative Soil Survey. 1997. Soil Survey of Lincoln County Area, Oregon. U.S. Government Printing Office. 256 p.

Pinheiro, J.C. and D.M. Bates. 2000. Mixed-Effects Models in S and S-PLUS. Springer-Verlag, New York, NY. 528 p.

Shinozaki, K, K. Yoda, K. Hozumi, and T. Kira. 1964. A quantitative analysis of plant form- the pipe model theory. I. Basic Analysis. Jpn. J. Ecol. (Nippon Seitai Gakkaishi) 14:97-105.

Stone, J., G. Chastagner, and A. Kanaskie. 2004. Control of Swiss needle cast in forest plantations by aerially applied elemental sulfur fungicide. P. 49-56 in Swiss Needle Cast Cooperative annual report. Mainwaring, D. (ed.). College of Forestry, Oregon State University, Corvallis, OR

Tassisa, G. and H.E. Burkhart. 1998. An application of mixed effects analysis to modeling thinning effects on stem profile of loblolly pine. For. Ecol. and Manage. 103:87-101.

Turner, J., M.J. Lambert, and S.P. Gessel. 1979. Sulfur requirements of nitrogen fertilized Douglas-fir. For. Sci. 25:461-467.

Waring, R.H., P.E. Schroeder, and R. Oren. 1982. Application of the pipe model theory to predict canopy leaf area. Can. J. For. Res. 12:556-560.

Weiskittel, A.R. 2003. Alterations in Douglas-fir crown structure, morphology, and dynamics due to Swiss needle cast in the Oregon Coast Range. M.S. Thesis, Oregon State University, Corvallis, OR.

Weiskittel, A.R. and D.A. Maguire. 2004. Influence of Swiss needle cast on Douglas-fir stem properties. P. 91-97 in Swiss Needle Cast Cooperative annual report. Mainwaring, D. (ed.). College of Forestry, Oregon State University, Corvallis, OR.

Weiskittel, A.R., D.A. Maguire, S.M. Garber, and A. Kanaskie. 2006. Influence of Swiss needle cast on foliage age-class structure and vertical foliage distribution in Douglas-fir plantations in north coastal Oregon. Can. J. For. Res. 36:1497-1508.

Williams, J.S. and R.M. Cooper. 2003. Elemental sulfur is produced by diverse plant families as a component of defense against fungal and bacterial pathogens. Physiol. Mol. Plant Path. 63:3-16.

Williams, M.S. and R.M. Reich. 1997. Exploring the error structure of taper equations. For. Sci. 43:378-386.

Yang, R.C. 1998. Foliage and stand growth responses of semimature lodgepole pine to thinning and fertilization. Can. J. For. Res. 28:1794-1804.

Developing spatial models for predicting Swiss needle cast distribution and severity

Jeff Stone and Len Coop

Department of Botany and Plant Pathology, Oregon State University

Introduction

Although it has long been considered an insignificant threat to forest health in the Pacific Northwest, an unusually severe and persistent outbreak of Swiss needle cast disease (SNC) has been affecting Douglas-fir plantations in the western Coast Range of Oregon since the mid 1990s (Hansen et al. 2000). The disease caused by the ascomycete fungus *Phaecryptopus gaeumannii* is responsible for premature needle loss in Douglas-fir and resultant cubic volume growth losses of 15 to 50%, depending on disease severity (Maguire et al. 2004). The disease currently affects about 150,000 ha of Douglas-fir plantations along the western flank of the Coast Range (Kanaskie et al. 2005). Because of its effects on Douglas-fir growth, Swiss needle cast is forcing changes in silviculture and management in forest lands in the western Coast Range of Oregon, and is an increasing cause for concern in areas not currently affected by the disease.

The causal organism, *P. gaeumannii*, has long been present at endemic levels in western Oregon but only brief, sporadic outbreaks of Swiss needle cast have been previously reported (Hansen et al. 2000). The relatively abrupt increase in SNC severity in Oregon has puzzled pathologists because *P. gaeumannii* is an endemic pathogen of a native host not previously associated with severe disease in forest plantations. The distribution of the disease has been attributed to increasing amounts of Douglas-fir being planted in the western Coast Range, particularly in areas where the natural forest type had historically been dominated by Sitka spruce and western hemlock. The area affected by SNC roughly corresponds to the area defined by the coastal spruce zone (Hansen et al. 2000).

A shift in abundance of Douglas-fir in the coastal spruce zone however, does not itself account for the distribution and severity of Swiss needle cast in the western Coast Range. The underlying causes of the current SNC epidemic, and what factors are most important in determining the abundance of *P. gaeumannii* and SNC severity, have remained an important outstanding question. Mechanisms that have been proposed include possible host physiological stress due to nutritional imbalances (Rose et al. 2001), involvement of a more agressive lineage of the pathogen in the epidemic area (Winton et al. 2001), and microclimate conditions conducive to pathogen growth and dispersal (Manter et al. 2005). Understanding the factors that influence SNC severity and their relative significance is essential to devising effective disease management approaches and for preparing for future changes in disease dynamics.

This study examines evidence from disease distribution records and empirical studies that microclimate effects are the main determinant of Swiss needle cast severity. The objective of this project is to identify specific climate variables that can be used to begin to develop spatial models for predicting SNC distribution and severity.

Methods

Aerial survey data from eleven years (1996 – 2006) of annual SNC aerial survey were combined to develop a cumulative disease distribution and severity map. The GIS package GRASS 6.0 (Neteler and Mitasova 2004) was used for spatial analysis in part due to its raster modeling capabilities. The severity codes were redefined for more consistent multi-year tracking according to the following rules:

1. For 1996, both L (low) and M (moderate) codes were recoded as "1"; H (High) was recoded as "2".
2. For 1996-2006, All non-SNC areas were recoded as "0" (not recorded).
3. For 1997-2000, L was recoded "1" and H was recoded "2". For 1999, D (discoloration not associated with SNC) was recoded "0".
4. For 2001-2006, M was recoded "1" and S (severe) was recoded as "2". For 2001, Z (other sources of discoloration) was recoded as "0".

Using these severity attributes, the data were first reprojected from LCC (Lambert Conformal Conic) to lat-long for compatibility with existing climate and vector datasets, then converted from vector to raster data at a resolution of 50 x 50 meters per grid cell. PRISM monthly precipitation, average temperature (daily max and min), and average dewpoint climate data (http://www.ocs.orst.edu/prism/) (2.5 arcmin or 4 KM resolution) were imported into GRASS for 1995-2006 and including the months suspected to impact SNC from earlier studies; May-Jul (spring-summer), and Dec-Mar (winter-early spring). Monthly mean relative humidity (RH) was then estimated from monthly average temperature and dewpoint. Other derived climate variables used for regression analysis included cumulative degree-days (3C lower threshold) for Dec-Feb and for Feb-Apr, Chilling Dds (0C upper threshold) for Dec-Feb, combined precipitation for May-Jul., average winter temperatures (Dec-Feb) and average RH for Jun-Jul. Elevation data used in the analysis included 30 sec (ca. 800 m) and 100 m resolution data.

The R statistical package (R Development Core Team 2006) was used to analyze correlation and regression models based upon these conventions: First, the cumulative additive SNC regions from the 11 years of survey data were taken as the area for analysis, to avoid the problem of knowing exact Douglas-fir distributions for any given survey year. If the disease was observed at a particular site during the 11 years of survey, it is assumed to be a Douglas-fir site and therefore included in the sample population. Second, dependent variables were assessed as either a) total area reported in the survey for each year, or b) average severity represented each year within the region represented over the entire 11 years survey. Third, independent variables were also averaged over the entire 11 year extent of positive SNC survey results. Routines used in the analysis included PLOT, to show pairwise scatter plots for all variables; the COR routine was used to find correlation coefficients among all variables, and the LM routine was used to find the best least

Table 1a. Relative humidity (RH), precipitation (PPT) data used to determine climate influence on SNC severity and extent, averaged over entire susceptible region of coastal Oregon Douglas Fir, 1996-2006.

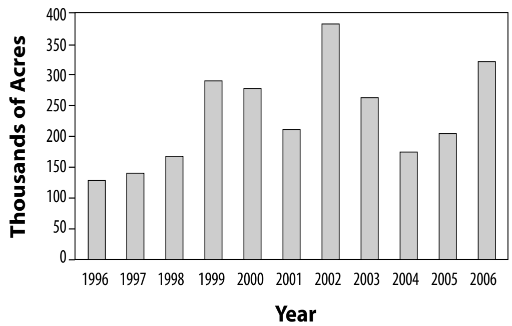
Year	RHJuJl	RHJun	RHJul	RHAvg	PPTMay	PPTJun	PPTJul	PPTMyJl	PPTMyJn
1996	71.2	72.5	69.9	72.27	68.9	98.1	14.1	181.1	167
1997	69.2	72.2	66.2	71.37	165.9	39.6	40	245.5	205.5
1998	75.9	78.4	73.4	74.5	101.1	116.8	43.7	261.6	217.9
1999	78.35	80.3	76.4	79.03	156.2	66.8	8.72	231.72	223
2000	76.4	77.4	75.4	76.2	178.5	70.5	21.8	270.8	249
2001	76.25	76.9	75.6	76.63	148	111.8	10.1	269.9	259.8
2002	76.3	76.9	75.7	75.3	89.9	99.2	18.1	207.2	189.1
2003	75.2	77.2	73.2	75.93	79.7	73.9	5.9	159.5	153.6
2004	70.4	69.9	70.9	72.27	72.6	18.9	6.2	97.7	91.5
2005	72.7	73.2	72.2	74.83	106.8	72.6	5.3	184.7	179.4
2006	74.4	77.1	71.7	75.23	165.5	97.5	27.4	290.4	263

Table 1b. Swiss Needle Cast extent (SNC) in sq. km, average severity (avg_sv), where 0=not reported, 1=light or moderate, 2=heavy or severe, winter average temperature (Wavg_t) for Dec-Feb, Degree-days (3C lower threshold) for Feb-Apr, averaged over entire susceptible region of coastal Oregon Douglas Fir, 1996-2006.

Year	SNC	avg_sv	Wavg_t	DDFeb	DDMar	DDApr	DDFeb-Apr	DDFeb-Mar
1996	528.23	0.14	6.46	3.91	5.46	7.25	16.62	9.37
1997	585.74	0.14	6.1	3.71	4.72	6.1	14.53	8.43
1998	700.91	0.2	7.03	4.76	5.44	5.99	16.19	10.2
1999	1192.74	0.35	5.77	3.17	3.59	5.43	12.2	6.76
2000	1146.3	0.3	6.49	4.18	3.87	7.26	15.31	8.05
2001	858.64	0.27	6.16	2.81	4.98	5.1	12.9	7.79
2002	1566.08	0.35	6.24	3.57	3.29	6.32	13.18	6.86
2003	1078.54	0.25	7.57	3.67	5.83	5.73	15.22	9.5
2004	716	0.16	6.63	4.3	6.36	7.99	18.66	10.66
2005	838.73	0.18	6.84	4.08	6.39	6.57	17.04	10.47
2006	1314.18	0.33	6.08	3.22	3.64	6.35	13.21	6.86

squares regression models using the AIC rule for variable inclusion/rejection. The final set of variables and values used in the regression analysis are displayed in Tables 1a and 1b.

A contract meteorologist (Fox Weather, LLC) interpreted cumulative SNC severity maps (the additive survey data) for a selected coastal area based upon typical coastal weather patterns during summer months. Fox Weather prepared a map showing such weather patterns and their likely influence on SNC severity. Further preliminary mesoscale models (CALMET + custom Fox Weather programs) were employed using weather data reanalysis techniques to quantitatively indicate how these trends can appear using actual weather data as an initial verification of interpreted weather patterns. More weather data reanalysis is needed to better summarize such patterns, to show how typical in regard to incidence, duration, and extent these are and how they will vary seasonally and therefore influence (or perhaps be missed by) resulting monthly climate data.



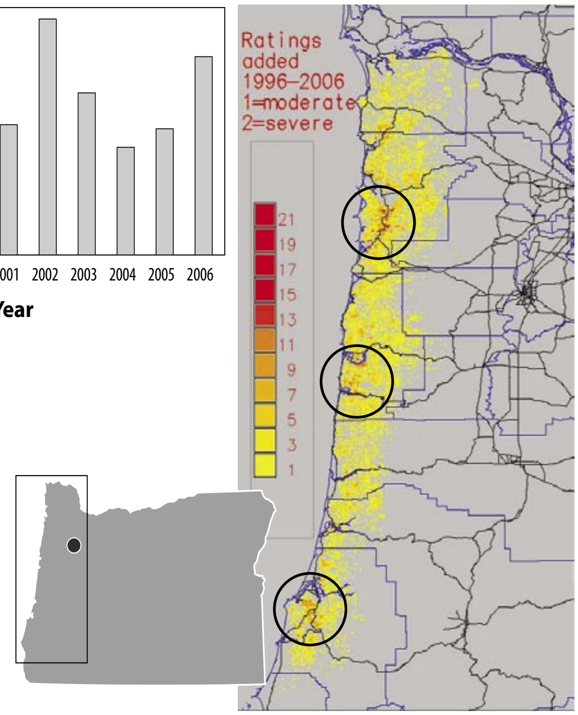


Fig. 1. Annual variation in SNC area in western Oregon (A) and combined (added) disease severity survey scores for W. Oregon coast (B). Legend signifies 1=disease moderate for single year to 22=disease severe all 11 years of survey. Circled areas highlight regions where chronic SNC has been observed. Source data: Oregon Department of Forestry.

Results and Discussion

Over the eleven years of aerial survey, a total of 474,000 ha in western Oregon were scored as having mild or severe Swiss needle cast symptoms. The total symptomatic area varied from 53,050 ha in 1996 to 156,630 ha in 2002. As has been reported previously (Kanaskie et al. 2001, 2004), the diseased area was limited mainly to a coastal strip extending about 30 km inland from the Columbia river to southern Coos Co. with greater symptomatic area and symptoms occurring further inland in the north (Figure 1).

The cumulative disease distribution map (Figure 1) also shows cumulative disease severity ratings. This is a visual estimate of disease severity based on overall color and defoliation in patches, scored as 0 (none), 1 (moderate symptoms), and 2 (severe symptoms). The average annual disease severity was positively correlated (R^2 = 0.86) with annual symptomatic area (Figure 2). This correlation suggests a relationship between annual variations in total affected area and symptom severity. Annual patterns of area affected by SNC and average severity appear to vary with annual weather conditions. Years in which a greater area is mapped also tend to have greater average severity.

A strong relationship between the yearly average SNC severity and the previous average summer (June and July) RH and late winter/early spring (Feb and March) degree-days was found (adj. R^2=0.76; p = 0.00011; Fig. 3). This model is similar to that of Manter et al. (2005), which was based on sentinel site data and nearby weather station observation data, but used summer leaf wetness duration rather than summer RH values. Summer RH, while highly significant in the model shown in Fig. 3., probably does not fully capture the more local and episodic conditions leading to leaf wetness-driven infection activity that is believed to be a major factor contributing to symptoms observed during the following spring survey.

A combined "SNC index" response variable, the product of total diseased area times average disease severity, was used as a response variable to compare annual disease trends with seasonally grouped climate factors. Observed disease distribution (SNC Index) was strongly correlated with a model that included the independent variables March degree days and July RH (R^2 = 0.76, Figure 4). This model is similar to the others but the July RH probably does not adequately reflect the physiological activity of leaf wetness on infection (July precipitation was also significant when used instead of RH in a model but adj. R^2 was slightly lower, 0.74); a more precise representation of leaf wetness would be preferable in a predictive model than either RH or precipitation (see below).

Previous studies (Rosso and Hansen 2003, Manter et al. 2005) have also identified seasonally grouped temperature and precipitation as factors related to spatial variations in SNC severity. July precipitation was one of the variables

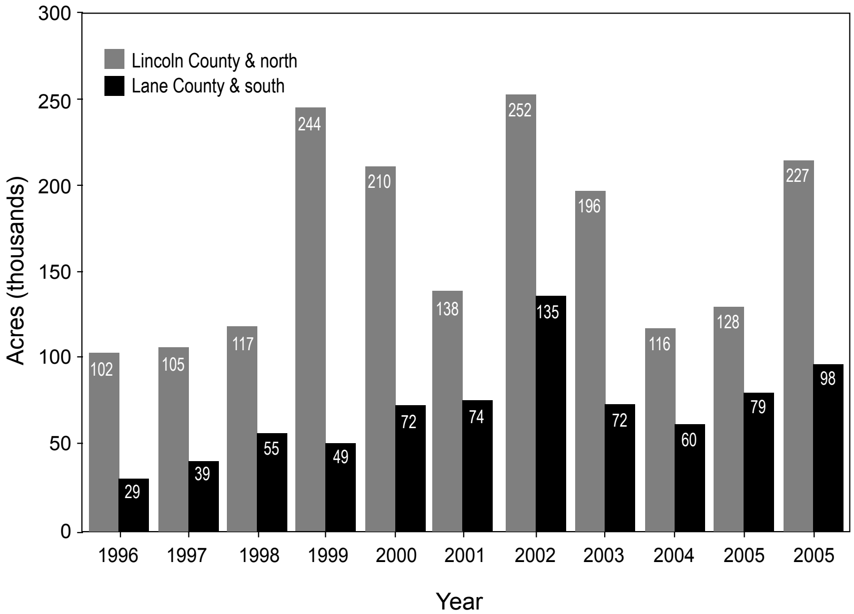


Fig. 2. SNC survey results 1996-2006: the relationship between total annual symptomatic area and average disease severity. Disease severity was rated as 0 (not present), 1 (low or light disease), 2 (heavy or severe disease). The sample population included all sites for which SNC symptoms (scored 1 or 2) were recorded in at least one year of the annual survey. For any location and year a "0" was assigned to a location if no symptoms were recorded in that year, but symptoms had been recorded there in at least one other year. Average annual severity was calculated as the sum of the areas scored in each of the disease rating (0, 1, 2) divided by the total sample area for that year.

included in the model of Rosso and Hansen (2003), which also included Jul maximum temperature, Jul fog occurrence and aspect. The Rosso and Hansen (2003) model was used to predict overall stand disease rating, a 1-6 rating based on visual disease symptoms, and had an R^2 of 0.60 for stands in the western Coast Range. The best-fit model of Manter et al. 2005 included mean daily temperature averaged for the months of Jan-Feb and leaf wetness hours averaged for the months May-Jul. These factors were found to be strongly correlated with variation in abundance of *P. gaeumannii* pseudothecia on foliage, and had R^2 of 0.78 and 0.77 for one- and two-year old needles, respectively. It should therefore be noted that different studies using different indicators of disease severity have all identified similar seasonal climate factors for explaining variation in disease severity.

Although seasonal temperature and precipitation are good general predictors for annual variation in SNC severity, cumulative disease distribution suggests that other factors are also involved. Cumulative disease severity ratings reveal an uneven distribution of sites where severe SNC has been observed repeatedly over the past eleven years. Areas of chronic disease are aggregated. Three areas where chronic, severe disease (coded red on Figure 1) has been observed are shown on Figure 1 (circles): south of Coos Bay, an area to the east of Toledo, and an area east of Tillamook. The distribution of chronic disease patches for the Tillamook area, shown in greater detail in Figure 5, appears to be strongly influenced by geographic features and topography. Areas of chronic, severe disease occur along valleys and drainages, tend to occur on south aspect slopes, and in a relatively narrow elevational band from 200 m and decreasing above 500 m.

Areas of chronic disease severity along valleys and in the western Coast Range foothills appear to coincide with areas subject to conditions that lead to greater leaf wetness in the early summer. Marine drizzle tends to be enhanced at elevations between 200 and 400 m

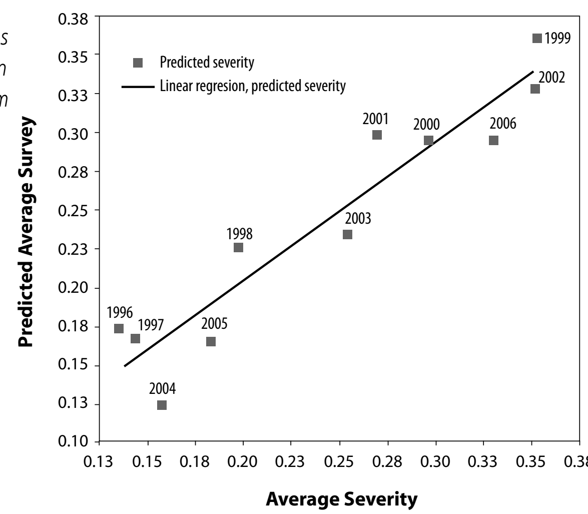


Fig. 3. Average yearly SNC survey severity (x-axis) vs. predicted based on average Jun-Jul RH and Feb-Mar degree-days (3ºC lower threshold).

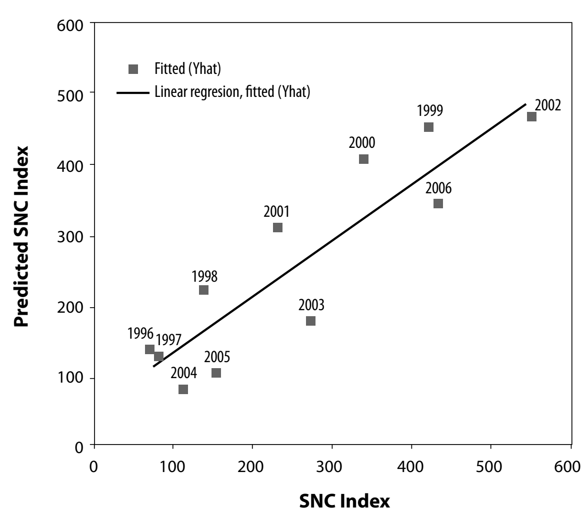


Fig. 4. SNC index (area with symptoms x average severity) vs. Mar. degree-days and July relative humidity. Model: SNC Index = -901.99 + 22.04 x Avg Jul RH - 91.84 x Degree-Days in March (F=16.9, p=0.001)

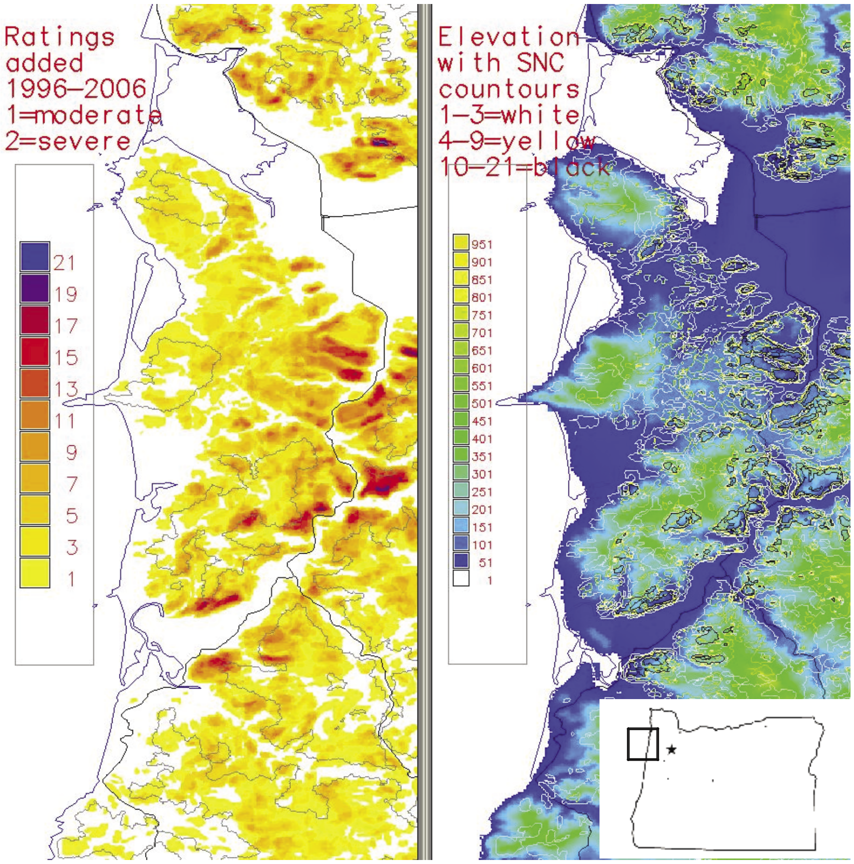


Figure 5. Closeups of Fig. 1 for the Tillamook area. Left side: blue is used to show the most chronic and severe SNC surveyed areas. Major roads in black and 200 m elevation contours in grey, shown for reference. Right side: elevation with legend showing aqua to blue for elevations 200 m and lower, with SNC severity contours where white is used for cumulative SNC of 1-3, yellow for SNC of 4-9, and black lines for SNC of 10-21. This figure helps to show most chronic areas on south facing slopes below 200 m. By comparing right and left sides, the non-random effects of coastal valleys and elevation are apparent.

due to the effect of orographic forcing. Convergence zones also occur in the near-surface wind field below the marine inversion. Convergence zones also have greater occurrence of clouds, fog and drizzle. Several areas of chronic severe disease in the area shown in Figure 5 occur in areas where onshore convergence would be expected (Figure 6).

Further efforts are under development to model summer weather patterns at mesoscale spatial resolutions in order to better quantify how coastal fog and drizzle related events can affect subsequent SNC severity. For example, the orographic-based Fox Weather, LLC custom precipitation model Mtnrtcon (contracted for use by OSU) is expected to quantifiably capture localized terrain-driven precipitation events that are relevant to SNC-influencing leaf wetness duration (Fig. 7). This spatial resolution could otherwise only be captured using a prohibitively expensive grid of closely spaced (ca. less than 1 km between adjacent sensors) leaf wetness sensors or other ground station based devices. Increasingly accurate and downscaleable meteorological models can instead provide these data.

This study represents some of the trade-offs in attempting a spatial modeling framework for Swiss needle cast. First, the relatively coarse spatial resolution of the PRISM climate data used here (ca. 4 KM) can be improved to ca. 800 m or better, which will allow for several changes to the approach we used. We modeled the overall year to year changes in extent and severity of SNC without respect to individual locations, thus we can predict next years overall average severity and total square kilometers of symptom expression, but not local or site-specific values. This study has helped to suggest that we should be able to make such predictions with both higher resolution spatial climate data, and with selected weather event reanalysis modeling tools, such as the model whose example output is shown in Fig. 7. On the other hand, lacking such data and tools, we would still be able to use our models to "scale up or down" the clear imprint of the recent cumulative surveys of SNC severity as displayed in Figs. 1, 5, and 6. But local weather does tend to vary from year to year, and our models, at this point, do not even utilize local weather variations represented by the 4 KM monthly climate data sets. Therefore yearly forecasts of SNC severity, and also the ability to develop better models for longer term SNC severity predictions, will greatly benefit from higher resolution input data, and from a more site-specific approach than we were able to perform with the current data sets. Site specific models that can be used for long term analysis can potentially be of significant use in determining management practices, such as where to thin and replant, and whether to select alternative tree species in a given location.

In summary, evidence is accumulating that annual and spatial variation in SNC distribution and severity can be explained by seasonal and annual weather patterns. Observed patterns of distribution of SNC in western Oregon are a result of longer term historical climate trends, and likely will be influenced by future climate trends. Research is continuing to identify climate factors that directly affect growth, dispersal, and infection by *P. gaeumannii* to better be able to predict trends in disease distribution.

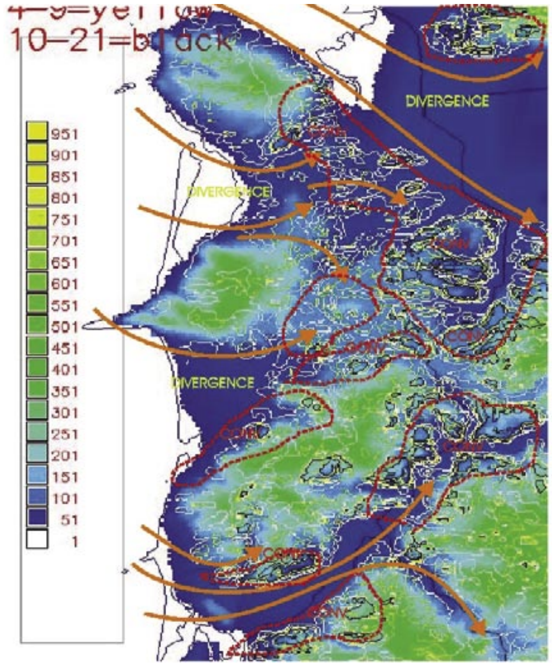


Fig. 6. Fox Weather, LLC analysis of weather patterns believed to contribute to SNC disease development, Tillamook area also represented in Fig. 5.

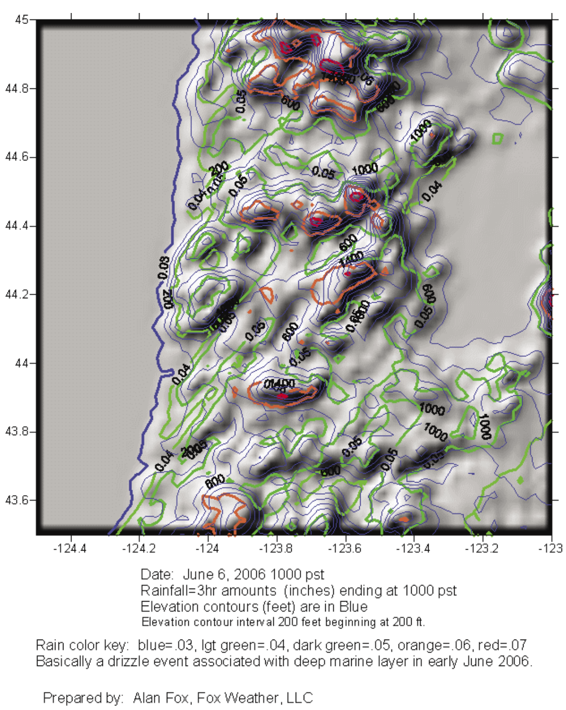


Fig. 7. Fox Weather, LLC weather model reanalysis of coastal deep marine layer event (June 6, 2006; from North at Lincoln City to just South of Florence) leading to localized precipitation in the form of fog and measurable drizzle, ranging from 0.03 to 0.07 inches of precipitation.

Literature Cited

Hansen, E. M., Stone, J. K., Capitano, B. R., Rosso, P., Sutton, W., Winton, L., Kanaskie, A., McWilliams, M. G., 2000. Incidence and impact of Swiss needle cast in forest plantations of Douglas-fir in coastal Oregon. Plant Disease 84: 773-778.

Kanaskie, A, M. McWilliams, K. Sprengel, and D. Overhulser. 2001. pp 7- 10 in: G. Filip, ed. Swiss needle cast cooperative annual report 2001.> College of Forestry, Oregon State University.

Kanaskie, A, M. McWilliams, K. Sprengel, and D. Overhulser. 2005. pp 9-11 in: D. Mainwaring and D. Shaw eds .Swiss needle cast cooperative annual report 2005. College of Forestry, Oregon State University.

Kanaskie, A., M. McWilliams, K. Sprengel, and D. Overhulser. 2005. Swiss needle cast annual surveys, 1996 to 2005. pp.9-11 in D. Mainwaring and D. Shaw (eds). Swiss needle cast cooperative annual report 2005. College of Forestry, Oregon State University.

Maguire, D., A. Kanaskie, and D. Mainwaring. 2004. Growth impact study: growth trends during the third 2-yr period following establishment of permanent plots. pp 24-27 in D. Mainwaring (ed.) Swiss needle cast cooperative annual report 2004. College of Forestry, Oregon State University.

Manter, D. K., Reeser, P. W., and Stone, J. K. 2005. A climate based model for predicting geographic variation in Swiss needle cast severity in the Oregon Coast Range. Phytopathology 95:1256-1265.

Neteler, M. and H. Mitasova "Open Source GIS: A GRASS GIS Approach. Second Edition." Boston: Kluwer Academic Publishers/Springer. 424pp, 2004.

R Development Core Team. 2006. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org.

Rose, C. L., K. Kavanagh, R. Waring, and D. K. Manter. 2001. Nutritional imbalances as a predisposing factor in Swiss needle cast disease. pp. 55-61 in G. M. Filip (ed.) Swiss needle cast cooperative annual report 2001. College of Forestry, Oregon State University.

Rosso, P. and E. M. Hansen. 2003. Predicting Swiss needle cast disease distribution and severity in young Douglas-fir plantations in Coastal Oregon. Phytopathology 93:790-798.

Winton, L. M., E. M. Hansen, and J. K. Stone. 2001. Population structure of *Phaeocryptopus gaeumannii*. pp. 22-27 in G. M. Filip (ed.) Swiss needle cast cooperative annual report 2001. College of Forestry, Oregon State University.

Are Differences in the Ectomycorrhiza Community Correlated with Swiss Needle Cast Severity?

Daniel L. Luoma and Joyce L. Eberhart

Introduction

Mycorrhizae are long-lived symbioses between fungi and the roots of higher plants. The fungi extend the nutrient-absorbing surface area of the roots; produce extracellular enzymes which increase phosphorous and nitrogen availability; increase host drought tolerance; and protect against pathogens. In return, the fungi receive host photosynthate as their main source of carbon. Ectomycorrhizal fungi (EMF) are essential for host plant nutrient uptake and play important roles in nutrient cycling in many forests (Cromack *et al.*, 1979). For example, an estimated 50 to 70 percent of the net annual productivity may be translocated to roots and associated mycorrhizal fungi (Norton *et al.*, 1990; Fogel and Hunt, 1979; Vogt *et al.*, 1982).

Exudates and hyphae of EMF form a major link between above-ground producers and soil food webs, providing carbon for a wide range of bacteria, protozoa, arthropods and microfungi. Mycorrhizal fungi are also important in above–ground food webs. EMF, with few exceptions, produce macroscopic sporocarps (mushrooms and truffles) that are important in the diets of animals, especially small mammals (Fogel and Trappe, 1978; Maser *et al.*, 1978; Carey 1991). Some rodents such as the California red-backed vole (*Clethrionomys californicus*) and northern flying squirrels (*Glaucomys sabrinus*) rely on these sporocarps for over 90% of their food supply (Hayes *et al.*, 1986; Z. Maser *et al.*, 1985) and are primary prey for species such as the Northern Spotted Owl.

Ectomycorrhizae and Silvicultural Manipulations

Ectomycorrhizal symbioses are formed on about 8000 plant species (Dahlberg, 2001) and the current estimate of the number of EMF species is 6000 (Molina et al., 1992). Most of the dominant and economically important timber species in the Pacific Northwest are EM dependent including all members of the Pine, Oak, and Birch plant families (Smith and Read, 1997). Douglas-fir alone has about 2000 EM fungal symbionts throughout its range (Trappe, 1977). Douglas-fir will not grow without ectomycorrhizal fungi. Figure 1 shows 3 year-old nursery seedlings, only

Figure 1. Growth response of nursery grown Douglas-fir from ectomycorrhizal fungi (J. Trappe photo, USDA Forest Service).

some of which have begun to grow after their roots became mycorrhizal (Trappe and Strand, 1969).

Ectomycorrhiza diversity is an important component of forested ecosystems for stabilizing below-ground processes after disturbances (Perry et al., 1989). Seedlings associated with a high diversity of EMF may be better able to adapt to disturbance when compared to seedlings with less EMF diversity (Simard et al., 1997). In addition, a high EM diversity seems to increase tree's competitive abilities. A laboratory study supported this hypothesis by documenting that *Pinus patula* seedlings inoculated with two species of EMF grew taller and put on more biomass then seedlings inoculated with only one EMF species (Sudhakara and Natarajan, 1997).

Several small studies have suggested a correlation between Swiss needle cast disease (SNC) severity and nutrient status of both soil and Douglas-fir foliage. References to extensive background information on the casual agent of SNC (*Phaeocryptopus gaeumannii)* may be found in Mainwaring and Shaw (2005). Although preliminary fertilization trials have not found evidence of nutritional amelioration of SNC, it is still plausible that imbalanced nutrition may contribute to the susceptibility of Douglas-fir to SNC. Research and experience in agriculture suggests that nutrients are not as available to plants if the soil microbial community is not in a stable and healthy condition. Ectomycorrhiza communities are particularly influential with respect to nutrient availability and tree nutrition, so may be potentially influential in predisposition of Douglas-fir to SNC.

Objectives

Given the interdependencies of tree health and mycorrhiza health, we hypothesized that SNC would affect mycorrhiza frequency and abundance. The contribution of poor mycorrhiza health to SNC disease symptoms is unknown. Our objective was to establish a pilot study to determine levels of ectomycorrhizae in forest stands with moderate to high levels of SNC disease.

Methods

We selected sites from those previously established and under study by the SNCC. Six pairs of stands from the Sulfur Study in Oregon were used (see Stone et al, 2005 for background on the Sulfur Study) and 5 stands of the control treatment from the Oregon Department of Forestry (ODF) Commercial Thinning Study (CTS) in Tillamook County were used (see Mainwaring et al., 2005 for background on the CTS). Table 1 lists the sites. One additional location was included to represent a site located in the Oregon Coast Range, but outside the zone of SNC disease symptoms. The Grassy Flat site was a managed stand of Douglas-fir about 40 yrs. old and exhibited 4 – 5 yrs. of needle retention. It was located in the headwaters region of the Nestucca River in Yamhill county on Bureau of Land Management land.

Table 1. List of SNCC sites used to assess ectomycorrhiza diversity. Treatment and control stands were sampled at the Sulfur Study sites. Only control stands were sampled at the ODF Commercial Thinning Study sites.

Sulfur Study	
Green Diamond	10
Green Diamond	25
Kansas Creek	25
Western Oregon	18
Starker	10
Starker	20
ODF Thinning Study	
Cook Wright	
Kilchis Lookout	
Schmitz	
Toll Road	
West Standard	

Six 5.5 x 15 cm soil cores were systematically collected from each stand. Roots were extracting by washing the soil sample in an elutriator and wet sieving. The contents of the sieve were spread evenly, with enough water to cover, in the bottom of a 38 x 17 x 2 cm tray that was divided into 36 compartments by an inserted Plexiglas partition (Eberhart et al., 1996). Roots were examined with a stereomicroscope at 15-30X magnification Each mycorrhizal type encountered was classified by morphological characteristics similar to those described in Ingleby et al. (1990) and Goodman et al. (1996) including color, texture, presence/absence of rhizomorphs and emanating hyphae. Morphotype identities were determined by comparison to the EM character database maintained by Eberhart et al. (1996). The total number of ectomycorrhiza types per soil core and total number of mycorrhizal root tips in each core were recorded for 4 soil cores from each stand. Representative samples of the predominant mycorrhiza types were saved in CTAB buffer for potential molecular analysis ("finger printing") of the fungal DNA.

Mean number of EM types per soil core and total number of EM tips per soil core were used as a response variables for ANOVA comparisons among the study class types. When appropriate, this was followed by the Tukey-Kramer honestly significant difference test to determine whether study classes differed from one another.

Results

Stands from the Sulfur Study had an average of 3.1 ectomycorrhiza (EM) types per soil core. This broke out to 3.0 types per core in the plots treated with sulfur and 3.2 types in the control plots, an non-significant difference ($p = 0.78$). Within the Sulfur Study plots there was also no difference by age class ($p = 0.61$).

The ODF stands had an average of 5.2 EM types/soil core and this mean was significantly different from the sulfur study mean EM types/soil core ($p = 0.001$). The Grassy Flat stand had an average of 6.8 EM types/soil core. Mean number of EM types/soil core was not different between Grassy Flat and the ODF plots ($p > 0.05$) but was different comparing Grassy Flat and the Sulfur Study ($p < 0.05$). The EM type richness results are summarized in Table 2. Counts of the number of ectomycorrhizal root tips per soil core followed a similar pattern (Figure 2).

A common measure of recent SNC disease severity across all study plots was not available. SNC infection index regressed against EM type richness in the Sulfur Study plots was not significant ($r^2 = 0.12$, $p = 0.22$). Needle retention time (yrs.) regressed against EM type richness in the ODF CTS plots was not significant ($r^2 = 0.05$, $p = 0.66$).

Discussion

To put our results in context, Figure 3 provides comparison of the mean number of EM types/soil core found in this study with results from other studies in the region that used the same soil core and EM type assessment methodology. The very low levels of EM diversity in the Sulfur Study plots was similar to that found in the Long Term Ecosystem Productivity (LTEP) experiment after a clearcut and burn in the Siskiyou Mts. of southwestern Oregon (Luoma and Eberhart, 2005). In that case, the limited amount of EM present were largely accounted for by stump-sprouting hardwoods such as tan oak and madrone. Mature stands of Douglas-fir in the Cascade and Siskiyou Mts. have 3-4 times greater EM type richness on a per-soil-core basis (Eberhart et al., 1996; Luoma et al., 2006) as compared to the Sulfur Study and ODF CTS stands (Figure 3.)

ODF CTS control stands had mean ectomycorrhiza richness similar to that of open areas in the Demonstration of Ecosystem Management Options (DEMO) experiment 15% dispersed green-tree retention units (Fig. 3). The DEMO soil samples were located 10-17 m from the nearest Douglas-fir retention tree. Additionally, EM density in the ODF stands was about 50% that of the DEMO 15%D treatment (Luoma et al., 2006). In general, EM density in the Sulfur Study and ODF CTS stands was < 10% of that found in 100 yr.-old Doug-fir dominated forests in the Cascade and Siskiyou Mts. (Luoma et al., 2006 and Luoma, unpublished data).

The lack of correlation between EM diversity and SNC disease as measured by needle infection index or needle retention time (yrs.) is likely attributable to the lack of a common measure of SNC disease severity across all plots and the need to examine a greater number of plots with lower levels of *Phaeocryptopus gaeumannii.*

In the 2006 aerial survey, four of the 12 Sulfur Study stands were classified as being in the zone with "severe" SNC symptoms with the remainder of the stands in the "moderate" zone. All of the ODF CTS plots fell into the "moderate" category zone. Therefore the difference in EM type richness between the Sulfur Study plots and the CTS plots is indirectly related to differences in average SNC symptoms as measured by the aerial survey. However, the CTS stands also represented an older age class (30-60-yr-old) than the Sulfur Study, so some of the EM differences may be attributable to stand age or other factors associated with stand development.

The levels of EM diversity found in this study indicate that the below-ground ecosystem has been strongly affected by SNC, by the previous removal of mature trees during timber harvest, by post-harvest silvicultural practices, or by a combination of all three. Comparison of EM diversity to naturally-regenerated young stands following stand-replacing disturbances may help separate harvest or natural disturbance effects from those of post-harvest silvicultural treatments. In short, more work would be necessary to establish whether the response of EM diversity is cause or effect. However, there was also indication that some EM

Table 2. Richness of EM types in samples grouped by study site.

	Mean # of types/soil core	Standard error
Sulfur Study, control	3.0a	0.5
Sulfur Study, treatment	3.2a	0.5
ODF Thinning Study	5.2b	0.7
BLM Grassy Overlook	6.8b	1.1

Means not sharing the same superscript letter are different at $p \leq 0.05$

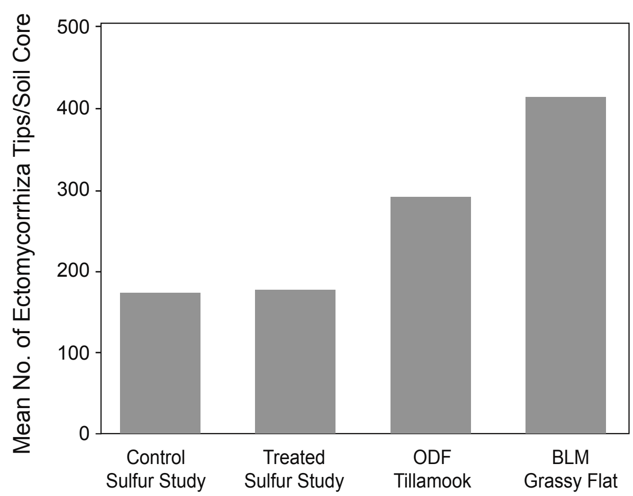


Figure 2. EM type richness found in several studies in western Oregon and Washington.

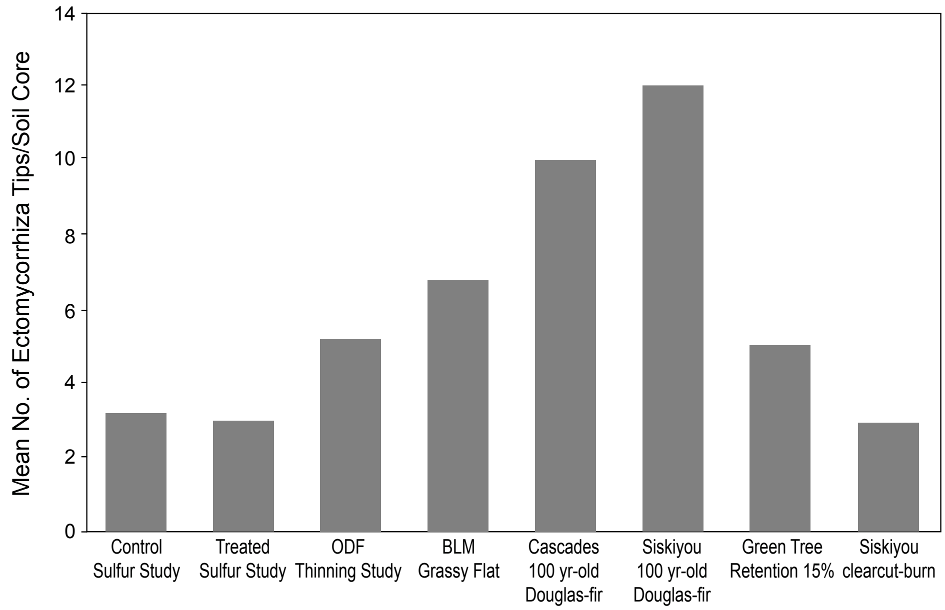


Figure 3. Density of EM in soil cores from SNCC study stands.

fungi may be "stress tolerators" (sensu Grime, 1979). Common Douglas-fir EM types such as *Cenococcum* and *Rhizopogon* were less wide spread in this study than in the DEMO or LTEP studies (Eberhart et al., 1996; Luoma et al., 2006). Because the SNC affected trees were mycorrhizal, albeit at low densities, we hypothesize that certain EM fungi have become more predominant on the roots that remain and are filling the important functional roles that EM play in tree nutrition. Studies to examine and test the hypothesis that "stress tolerant" EM fungi are important to keeping Douglas-fir alive in the face of SNC disease would seem to be warranted. Our results also suggest that measurements of the EM community may be useful to monitor the health of forest stands in efforts aimed at early detection of SNC susceptibility.

References

Carey, A. B. l991. The biology of arboreal rodents in Douglas-fir forests. Gen. Tech. Rep. PNW-GTR-276. USDA Forest Service, Pac. NW. Res. Stn., Portland, OR. 46 pp.

Cromack, K.; Sollins, P.; Graustein, W.C.; Speidel, K.; Todd, A.W.; Spycher, G.; Li, C.Y.; and Todd, R.L. 1979. Calcium oxalate accumulation and soil weathering in mats of the hypogeous fungus *Hysterangium crassum*. Soil Biol. and Biochem. 11: 463-468.

Dahlberg, A., and Stenström, E. 1991. Dynamic changes in nursery and indigenous mycorrhiza of *Pinus sylvestris* seedlings planted out in forest and clearcuts. Plant and Soil 136:73-86.

Dahlberg A. 2001. Community ecology of ectomycorrhizal fungi: an advancing interdisciplinary field. New Phytologist 150: 555-562.

Eberhart J.L, D.L. Luoma and M.P. Amaranthus. 1996. Response of ectomycorrhizal fungi to forest management treatments—a new method for quantifying morphotypes. In C. Azcon-Aquilar, Barea J.M. (ed.), Mycorrhizas in integrated systems: from genes to plant development. Pages 96-99. Office for Official Publications of the European Communities, Luxembourg.

Fogel, R.; and Hunt, G. 1979. Fungal and arboreal biomass in a western Oregon Douglas-fir ecosystem: Distribution patterns and turnover. Can. J. For. Res. 9: 245-256.

Fogel, R.; and Trappe, J.M. 1978. Fungus consumption (mycophagy) by small animals. Northwest Sci. 52: 1-31.

Goodman D.M., D.M. Durall, and Trofymow J.A. 1996. Describing ectomycorrhizae. In D.M. Goodman, D.M. Durall, J. A. Trofymow and S.M. Berch (eds), A manual of concise descriptions of North America ectomycorrhizae. Mycologue Publications, Sydney, BC.

Grime, J.P. 1979. Planat Strategies and vegetation processes. John Wiley & Sons, New York.

Hayes, J.P.; Cross, S.P.; and McIntire, P.W. 1986. Seasonal variation in mycophagy by the western red-backed vole, *Clethrionomys californicus*, in southwestern Oregon. Northwest Sci. 60: 250-257.

Ingleby, K., Mason, P.A., Last, F.T., and Fleming, L.V. 1990. Identification of ectomycorrhizas. Institute of Terrestrial Ecology, Res. Pub. No. 5. Midlothian, Scotland.

Luoma, D.L., and Eberhart, J.L. 2005. Forests, fire, and fungi. Joint Annual Meetings of the Mycological Society of America and the Mycological Society of Japan, Hilo, HI. July 30 – Aug. 4.

Luoma, D.L., Stockdale, C.A., Molina, R., and Eberhart, J.L. 2006. The spatial influence of Douglas-fir retention trees on ectomycorrhiza diversity. Canadian Journal of Forest Research, IN PRESS.

Mainwaring, D. and Shaw, D. (eds.). 2005. Swiss Needle Cast Cooperative Annual Report 2005, College of Forestry, Oregon State University

Mainwaring, D., Maguire, D., Kanaskie, A., and Brandt, J. 2005. Interactive effects of Swiss needle cast and commercial thinning on Douglas-fir growth and development in north coastal Oregon: two year response from 30 permanent monitoring plots, 2005. Swiss Needle Cast Cooperative Annual Report 2005, College of Forestry, Oregon State University.

Maser, C., Trappe, J.M., and Nussbaum, R.A. 1978. Fungal-small mammal interrelationships with emphasis on Oregon coniferous forests. Ecology 59(4):799-809.

Maser, Z.; Maser, C.; and Trappe, J.M. 1985. Food habits of the northern flying squirrel (*Glaucomys sabrinus*) in Oregon. Can. J. Zool. 63: 1084-1088.

Molina R., Massicotte H., and Trappe J.M. 1992. Specificity phenomena in mycorrhizal symbiosis: Community-ecological consequences and practical implications. In. Rourledge AMF, ed, Mycorrhizal Functioning, an integrated plant-fungal process. New York, USA: Chapman and Hall, inc.

Norton, J.M.; Smith, J.L.; and Firestone, M.K. 1990. Carbon flow in the rhizosphere of Ponderosa pine seedlings. Soil Biology and Biochemistry 22, 449-455.

Perry D.A., Amaranthus M.P., Brochures J.G., Brochures S.L., and Brained, R.E. 1989. Bootstrapping in Ecosystems: Internal interactions largely determine productivity and stability in biological systems with strong positive feedback. BioScience 39: 230-237

Simard S.W., Perry D.A., Smith J.E., and Molina R. 1997. Effects of soil trenching on occurrence of ectomycorrhizae on *Pseudotsuga menziesii* grown in mature forests of *Betula papyrifera* and *Pseudotsuga menziesii*. New Phytologist 136: 327-340

Smith, S.E. and D.J. Read. 1997. Mycorrhizal symbiosis, 2nd ed. London, UK: Academic Press.

Stone, J., Chastagner, G., and Kanaskie, A. 2005. Control of Swiss needle cast in forest plantations by aerially applied elemental sulfur fungicide. Swiss Needle Cast Annual Report, College of Forestry, Oregon State University.

Sudhakara M., and Nararajan K. 1997. Coinoculation efficacy of ectomycorrhizal fungi on *Pinus patula* seedlings in a nursery. Mycorrhiza 7: 133-138

Trappe J.M. 1977. Selection of fungi for ectomycorrhizal inoculation in nurseries. Annual Review of Phytopathology 15: 203-222

Trappe, J. M. and Strand, R. F. 1969. Mycorrhizal deficiency in a Douglas-fir region nursery. Forest Sci. 15: 381-389.

Vogt, K.A.; Grier, C.C.; Meier, C.E.; and Edmonds, R.L. 1982. Mycorrhizal role in net primary production and nutrient cycling in *Abies amabilis* ecosystems in western Washington. Ecol. 63: 370-380.